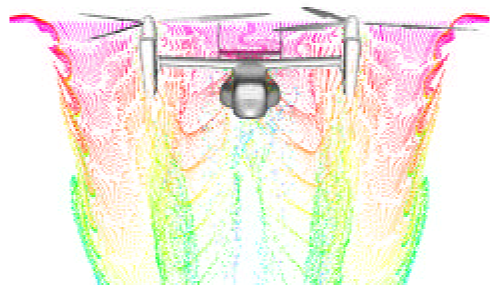
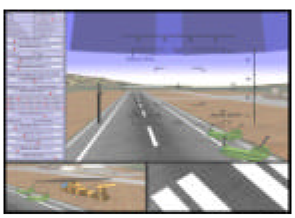
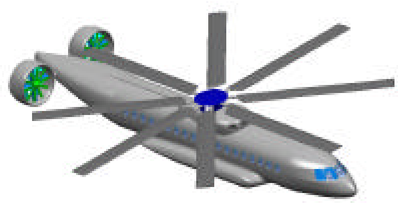
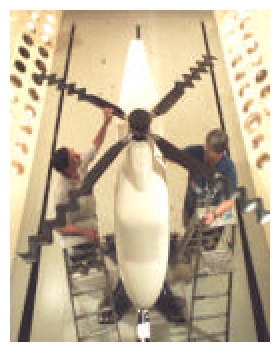
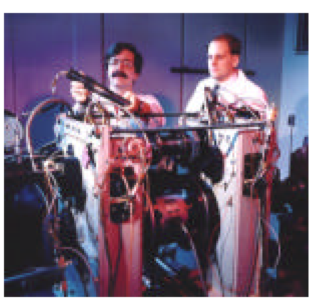
NASA Rotorcraft Technology Transition Workshop











September 5-6, 2001

NASA Ames Research Center

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, CA 94035-1000

September 5, 2001

Friends of Rotorcraft:

Thank you for attending the Rotorcraft Technology Transition Workshop.

We are conducting this workshop as part of the orderly phase-out of the Rotorcraft Base Program. The program represents a NASA investment of more than $100 million over the past five years – our purpose today is to obtain maximum value for that investment.

The presentations summarize some of the key accomplishments of the program, and these notes include a bibliography listing publications associated with each presentation. The Rotorcraft Program comprises four projects executed by participants at the Ames, Langley, and Glenn research centers working with the Department of the Army, Federal Aviation Administration, a number of universities, and contractors:

- RAPID – Revolutionary Approaches the Produce Innovative Design Technologies
- SILNT – Select Integrated Low-Noise Technologies
- SAFOR – Safe All-weather Flight Operations for Rotorcraft
- NRTC – National Rotorcraft Technology Center

The desired outcomes of today's meeting are to inform you of the work accomplished and research results available, to identify technologies that can be transitioned into products or, where appropriate, into further research and development, and to establish actions that will further these goals. To that end, I urge you to arrange breakout meetings, teleconferences, and other activities with the NASA managers and technical team leaders as you desire.

We thank you again for coming to Ames and for the support you've shown over the years. Please contact me at any time if we can help you or answer questions.

Sincerely,

John J Coy

Dr. John J. Coy
Manager
NASA Rotorcraft Base R&T Program
Telephone: (650) 604-3122
E-mail: jcoy@mail.arc.nasa.gov

NASA ROTORCRAFT TECHNOLOGY TRANSITION WORKSHOP

September 5-6, 2001

NASA Ames Research Center

Purpose:

1. To review and make available results of research accomplished by the NASA Rotorcraft Program
2. To identify opportunities for transitioning further development of selected technologies to other entities
3. To identify and facilitate the necessary actions for these transitions

Agenda:

Wednesday, Sep. 5

08.30 Welcome, purpose of meeting

08.45 RAPID (Bob Kufeld)

10.00 Break

10.15 SILNT Langley tasks (Mike Watts)

11.30 SAFOR Ames tasks (Laura Iseler)

12.15 Lunch

13.30 GRC RAPID, SILNT, SAFOR tasks (Jim Zakrajsek)

15.15 NRTC (Steve Dunagan)

16.00 Organize breakout meetings - identify issues & participants

16.30 Adjourn

Thursday, Sep. 6

08.00 Breakout meetings

12.00 Lunch

13.00 Wrap-up, summarize planned actions

13.30 Adjourn

Contacts:

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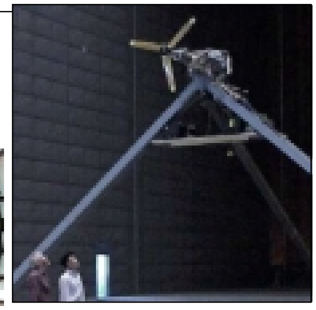
Dr. Stephen Dunagan, NRTC Project Manager, (650) 604-4560, sdunagan@mail.arc.nasa.gov

Revolutionary Approaches to Produce Innovative Design Technologies

Sept 5, 2001

Robert M. Kufeld, Project Mgr.

Project Overview

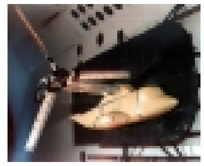


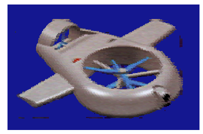
Project Goal

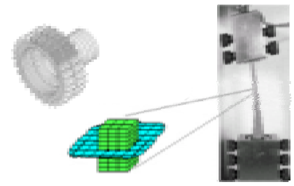
Revolutionize vertical flight & design to enable vertical flight as a solution to the Nation's "throughput and mobility" problems.

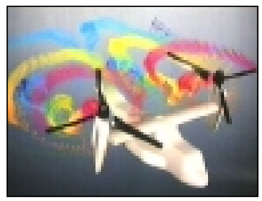
Objectives

1. Develop validated, fast, accurate, physics-based models design tools for
   1. aeromechanics predictions of revolutionary rotor concepts
   2. composite structures
   3. transmission fatigue life prediction
2. Integrate emerging design tools and processes into industry for the design of revolutionary rotary wing vehicle.









Benefit

Significant reductions in development time, cost of operation and ownership, and cost per passenger mile while increasing passenger acceptance of vertical lift vehicles.

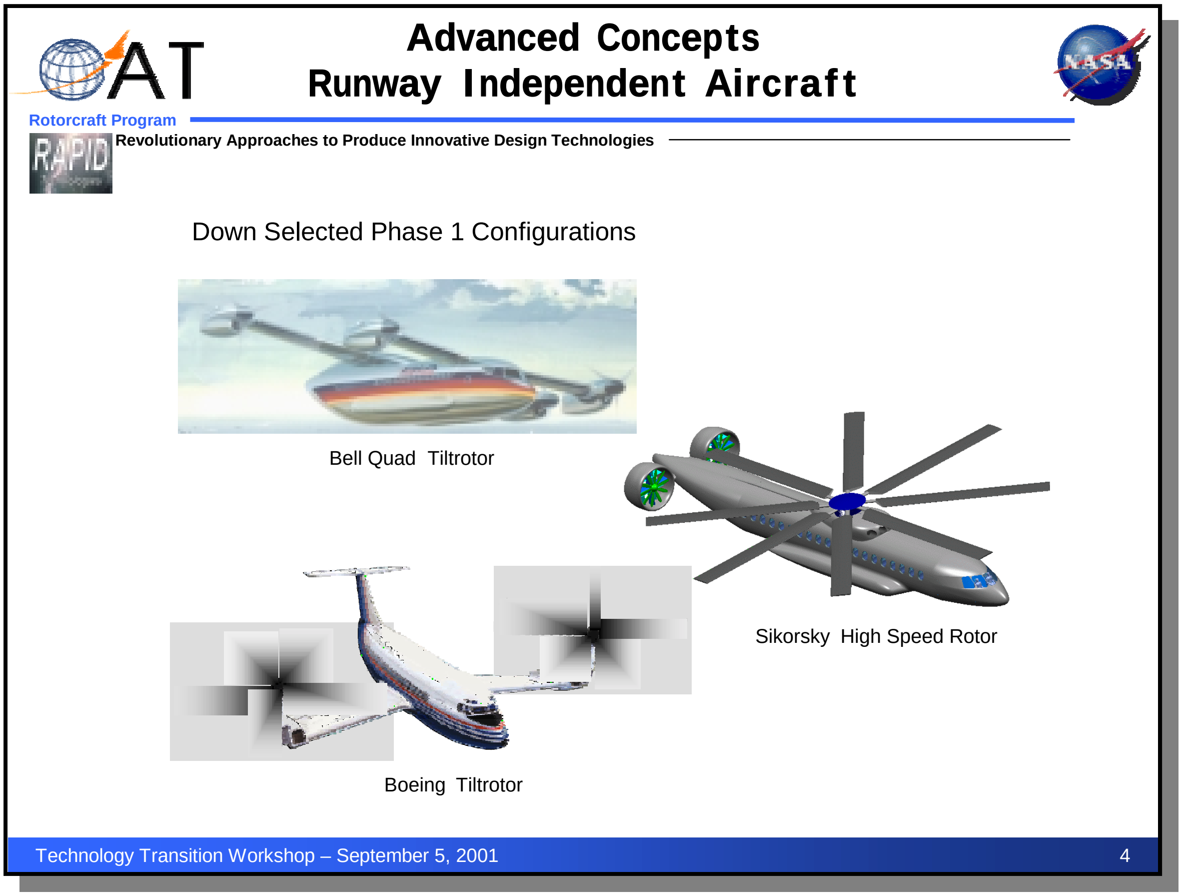
- **Aeromechanics**
- **Composite Structures**
- **Transmissions**
- **Physics-based Design Tools**
- **Revolutionary Concepts**
- **Experimental Validations**

RAPID/SILNT Projects
Ames Research Center

Rotorcraft Program

Revolutionary Approaches to Produce Innovative Design Technologies

- Advanced Configurations
  - Runway Independent Aircraft Concepts
  - Parametric Design/Cost Model
  - Variable Diameter Tilt Rotor Demonstrator
  - Swashplateless Flight Demonstrator
  - Ducted Fan
- Physics-Based Models Development
  - Modeling of Rotorcraft Aerodynamics
  - Modeling and Validation of Hovering Rotor
  - Real Time Rotorcraft Free Wake Modeling
  - UH-60 Airloads
  - Unsteady Aero
  - Applied Particle Image Velocimetry
- Tilt Rotor Aerodynamic/Acoustic
  - Tiltrotor Aeroacoustic Model
  - Adaptive Flow Control/Download Reduction
  - Tiltrotor Descent Aerodynamics 80x120
  - Tiltrotor Descent Aerodynamics 7x10
  - Tiltrotor Aeromechanics Assessment Committee
- Noise/Vibration control
  - Active Noise Controller Development
  - Individual Blade Control
  - Smart Rotor
  - Active Elevon Rotor
  - Intelligent Noise and Vibration Control



Goal

The goal of these design studies is to developed information that will identify technology barriers, payoffs, and priorities for future rotorcraft research. The study will provide initial information on a range of conceptual designs of advanced vertical lift solutions that could serve as part of the national air transportation system. This information is intended to:

1. Identify candidate solutions that embody advanced vertical flight technology
2. Enable selected solutions to be assessed using the NASA systems analysis models to determine the potential benefits of vertical flight as part of the air transportation system
3. Establish goals for future research in vertical flight technology

These solutions should be capable of providing attractive, reliable, and affordable service from vertiports, general aviation airports, or hub airports in simultaneous non-interfering operations. This supports NASA's goals for Capacity and Mobility.

Accomplishments to Date

Three contractor completed assessment of a wide verity of concepts for a 200-to 600 mile transport carrying 40 to 120 passengers judging them with Cost per seat mile, noise, speed, and reported results. Currently each contractor doing detail study of the down selected concept.

Future Plans / Opportunities

Complete detail study and report results and incorporate findings into NASA's Air Transportation System Study.

POC

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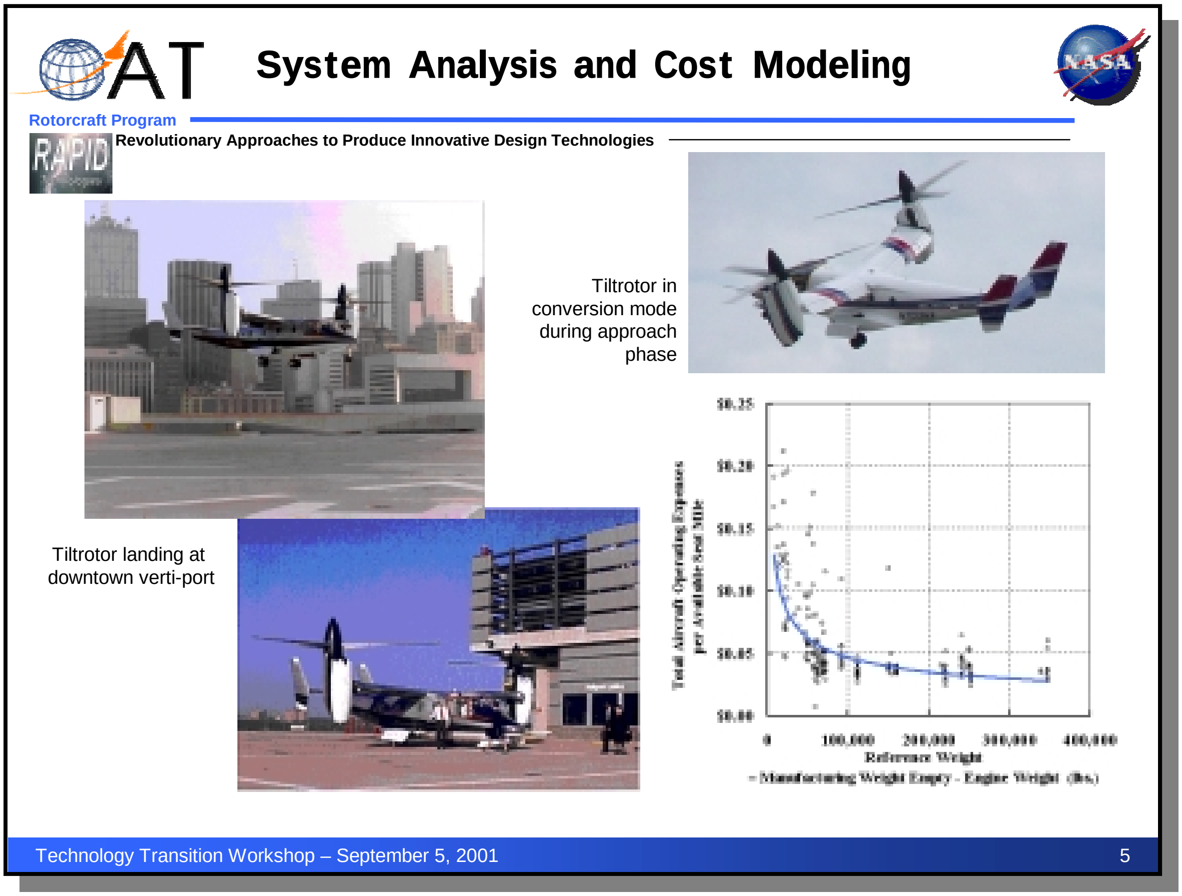


Goal

Develop an in-house capability to predict the cost and performance of conventional and advance rotorcraft as they operate within the National transportation system This supports NASA's goals for Capacity and Mobility.

Accomplishments to Date

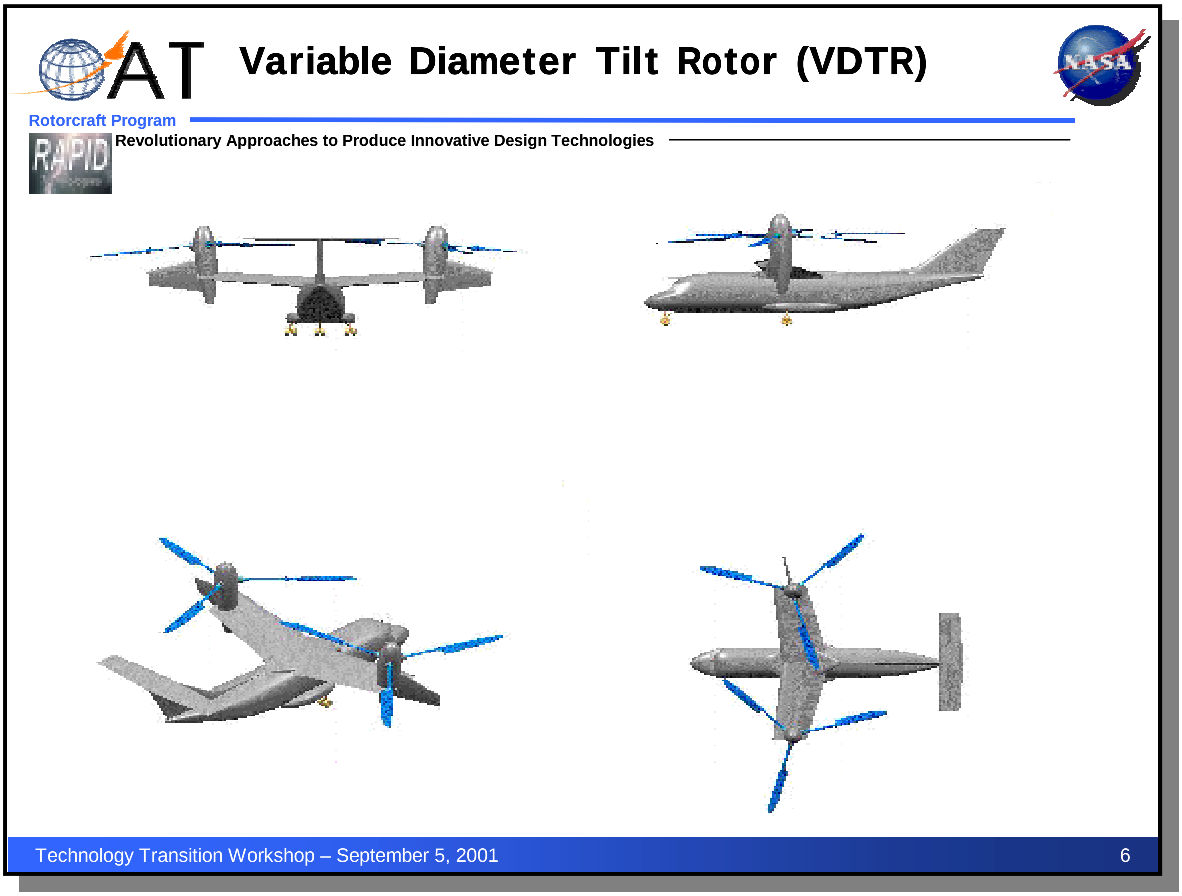
The source code for VASCOMP (1986,1997,2000) and HESCOMP parametric design codes were obtained and studied. Develop and improved the VASCOMP input glossary using Spreadsheet macros to facilitate the generation of input parameters. Updated the 1983 documentation. Exercised HESCOMP and VASCOMP programs for advance rotorcraft to ensure the codes were operational. Studied the commercially available cost data for airliners to validate existing cost models and make improvements to the cost model trend equations.

Future Plans / Opportunities

Improve the cost model for rotorcraft by expansion of the number of cost trend equations as function of design and performance parameters. Complete documentation update. Perform parametric design studies for advanced rotorcraft using the HESCOMP and VASCOMP codes.

POC

Johannes M. van Aken Ames Research Center (650) 604-6668 jvanaken@mail.arc.nasa.gov`



Goal

The goal of this work is to build a small-scale flight demonstrator to assess the feasibility of using VDTR to help solve national air transportation system problem. The VTDR will provide better hover and forward flight performance that regular tilt rotors thus providing better operating cost. This supports NASA's goals for Capacity, Mobility and Technology Innovation

Accomplishments to Date

Completed conceptual design layout of the proposed demonstrator and submitted report on performance for inclusion in the national air transportation system study.

Future Plans / Opportunities

Plans include building a flight demonstrator, testing in wind tunnel, and flight testing and reporting results if Phase II REVCON funding is approved.

Partners

NASA REVCON, Sikorsky

POC

John Madden, Ames Research Center, (650) 604-4590, jmadden@mail.arc.nasa.gov

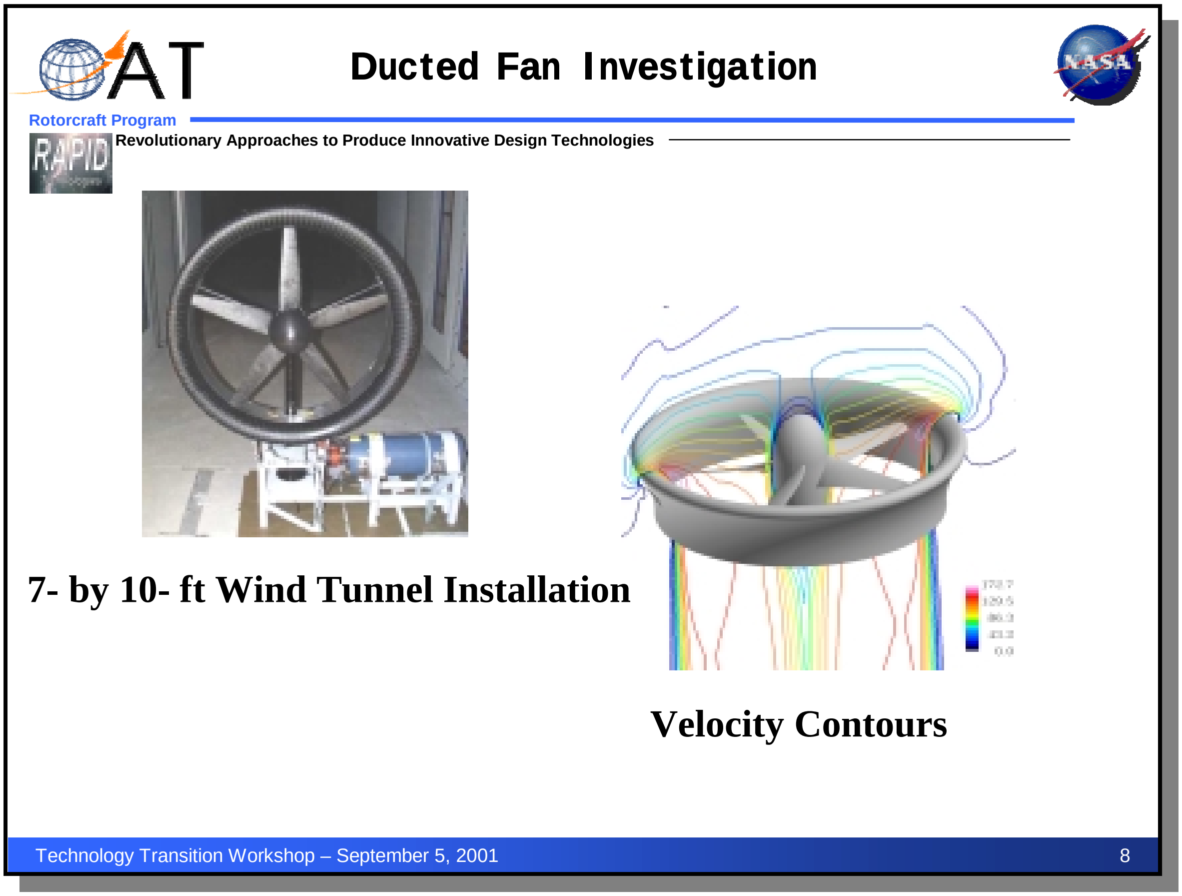
Goal
The goal of this work is to build a small-scale flight demonstrator to assess the feasibility of using Swashplateless control to help solve national air transportation system problem. The swashplateless rotor will provide individual blade control and reduce maintenance, improving performance, and reducing operating cost. This supports NASA's goals for Capacity, Mobility and Technology Innovation

Accomplishments to Date
Completed conceptual design layout of the proposed demonstrator, complete construction of fuselage, and submitted report on performance for inclusion in the national air transportation system study.

Future Plans / Opportunities
Plans include completing a flight/wind tunnel test vehicle, testing in wind tunnel, flight testing computational modeling and reporting results if phase II REVCON is approved.

Partners
NASA REVCON

POC
Khanh Nguyen, Ames Research Center, (650) 604-5043, knguyen@mail.arc.nasa.gov



Goal
The goal of the work is to evaluate performance of an alternative lift system for a microvehicle lift platform. This supports NASA's goals for Mobility and Technology Innovation.

Accomplishments to Date
A wind tunnel test was used to study the effects of ducted fan geometry and a CFD analysis was used to provide a baseline for correlation with experimental measurements.

Future Plans / Opportunities
Document results of test. A paper will be given this January at AHS Aeromechanics Conference in San Francisco. Assess the adequacy of design for microvehicle.

Partners
Millennium Jet, DARPA

POC
Anita Abrego, Ames Research Center, (650) 604-2565, aabrego@mail.arc.nasa.gov

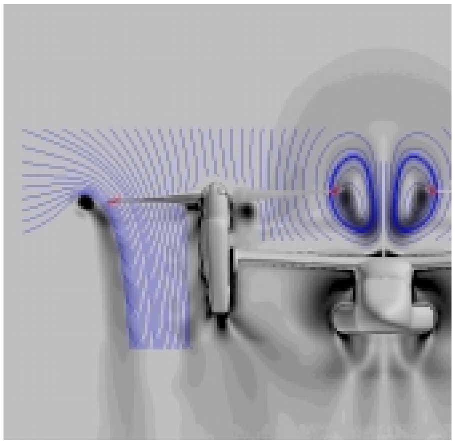
Rotorcraft Program

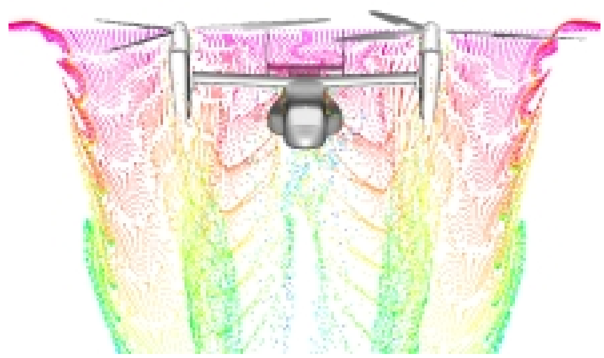
RAPID

Revolutionary Approaches to Produce Innovative Design Technologies

Computational Modeling
Rotorcraft Aerodynamics

CFD Calculated Hover Flowfields





V-22
Vorticity contours (B/W) and confined streamlines (blue)

VDTR
Time dependent particle traces

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Goal

The goal of the work is to develop advance Computational Fluid Dynamics tools and applied them to complex configuration. This work supports NASA's goal for Technology Innovation.

Accomplishments to Date

Completed comparison of baseline V-22 and Variable Diameter Tilt Rotor (VDTR) hover flowfields and performance using large-scale, high fidelity, turbulent flow, moving body simulation. The CFD tool development resulted in an average reduction in computational cost on parallel processors of 50%.

Future Plans / Opportunities

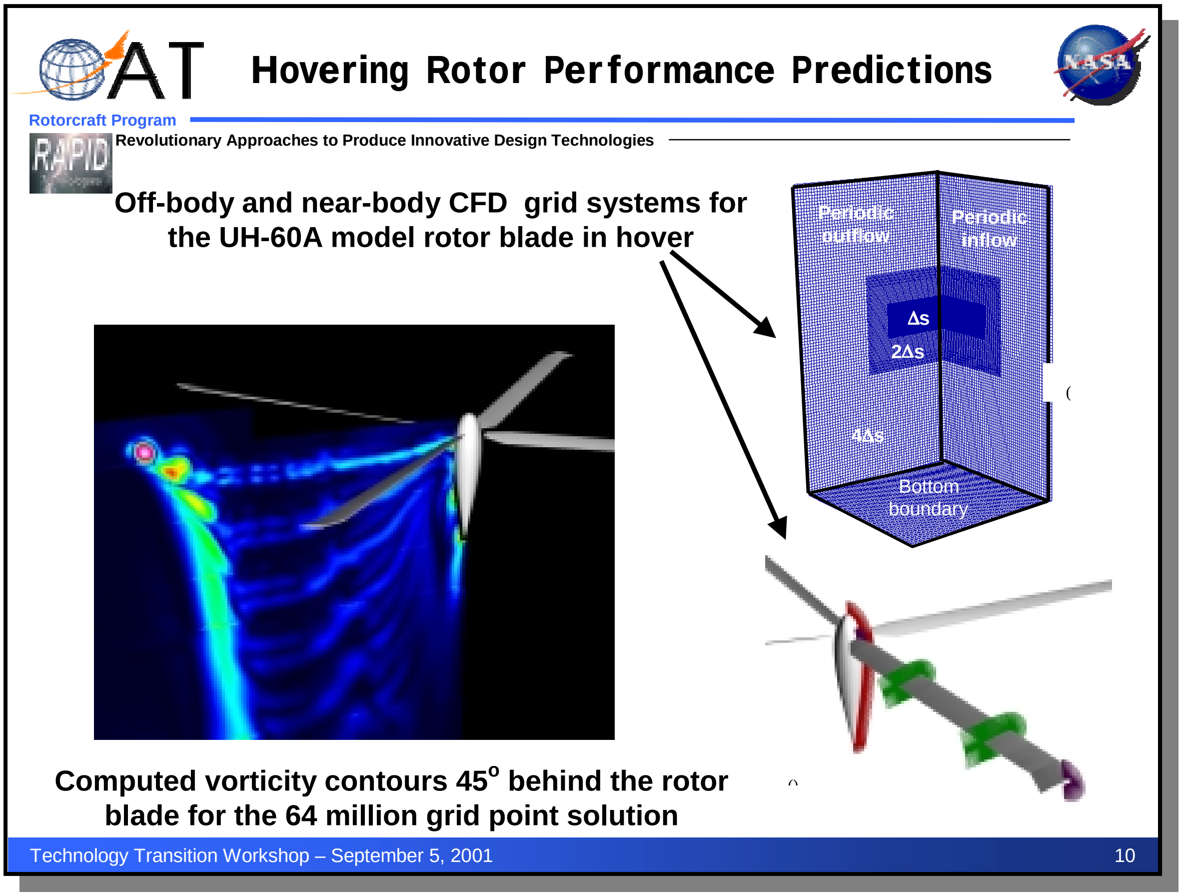
Improve dynamic CFD simulation with efficiency and ease of use enhancements and demonstrate CFD tool on NASA information Power Grid

Partners

Army, DARPA

POC

Mark Potsdam, Ames Research Center, (650) 604-4455, mpatsdam@mail.arc.nasa.gov



Goal

Validations of large-scale computation tool to predict the performance of an UH-60 rotor in hover with high numerical resolution to carefully control numerical effects and accuracy. This work supports NASA's goal for Technology Innovation.

Accomplishments to Date

Large-scale computations have been conducted. Baseline computation used 10.6 million grid points and one high-resolution simulation used 64 million points. The 64 million grid points pushes the limit of current high performance computer capacity. All solutions show very good agreement with experimentally measured rotor performance. The computations show the high-resolution grid can produce high-accuracy performance results and a wealth of detailed flowfield information.

Future Plans / Opportunities

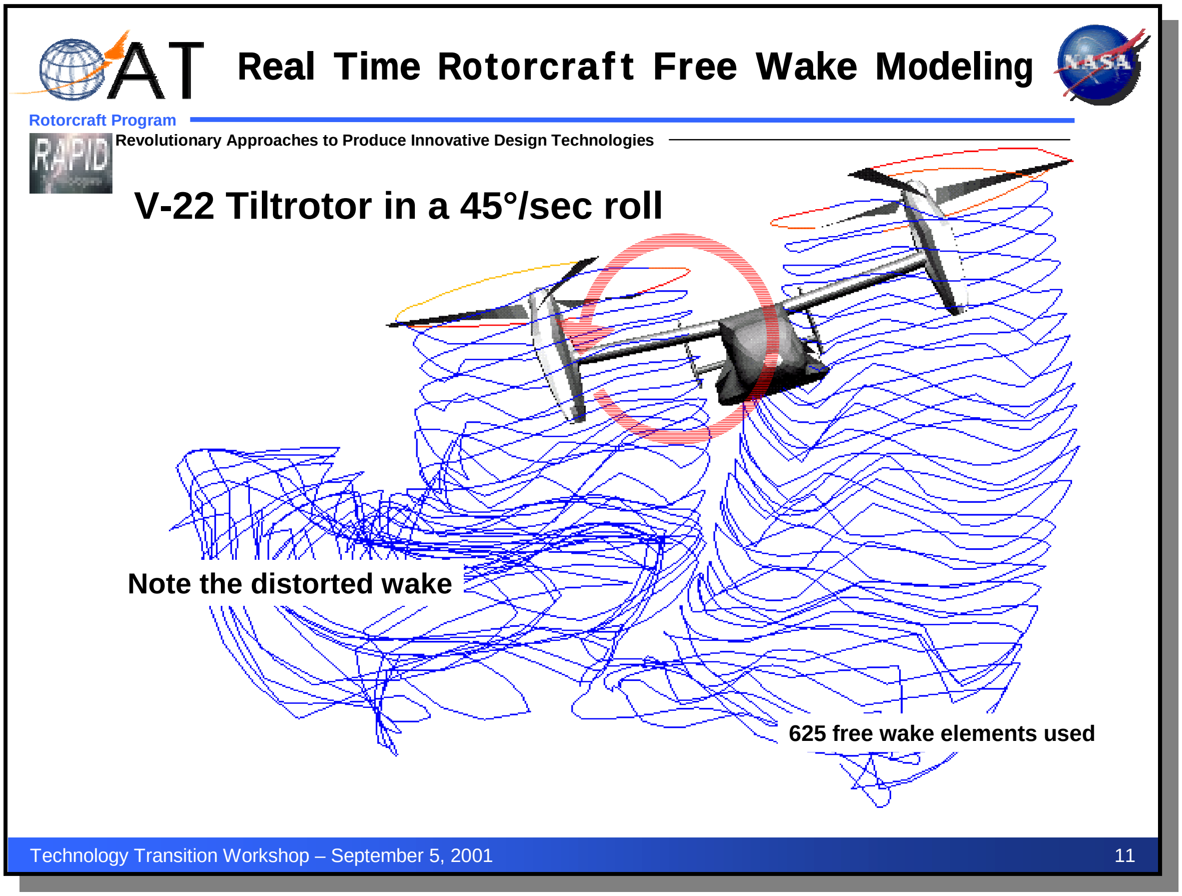
Develop code for computation on massively parallel computer to prepare for validation efforts on more complicated unsteady rotor simulations in forward-flight.

Partners

Army

POC

Dr. Roger Strawn, Ames Research Center, (650) 604-4510, rstrawn@mail.arc.nasa.gov



Goal
Develop complex, realistic rotor wake algorithms with fast CPU cycles time to enhance real time rotorcraft simulation used to support control system design and crew training. This work supports NASA's goal for Technology Innovation.

Accomplishments to Date
The aerodynamic wake models have been completed and can now support high fidelity, real time simulation of free wakes from rotorcraft. This capability has been demonstrated on both a conventional stand-alone serial processing workstation as well as in a code "module" to Sikorsky's GenHel full rotorcraft simulation.

Future Plans / Opportunities
Validation for the real time free wake module will be carried out by CDI and Sikorsky, simulating steady and maneuvering flight in GenHel. Project reporting, model documentation and training of NASA personnel will be completed soon.

Partners
CDI (NASA SBIR Program)

POC
Tom Norman, Ames Research Center, (650) 604-6653 tnorman@mail.arc.nasa.gov

AT

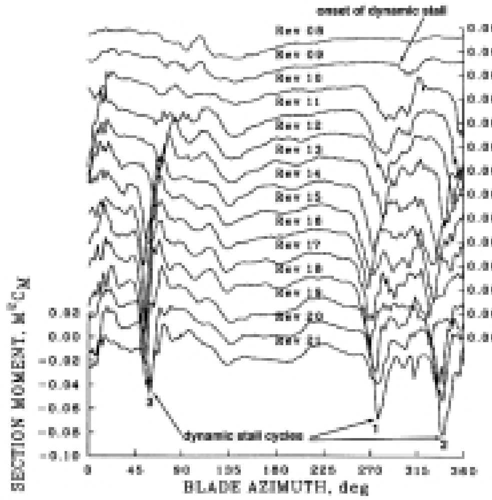
UH-60 Airloads Project

Rotorcraft Program

RAPID Revolutionary Approaches to Produce Innovative Design Technologies

UH-60 UTTAS Maneuver

Section moment at r/R = 0.865



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Goal

The goal is to obtain comprehensive, accurate, documented airloads over the complete operating limits of the UH—60 rotor system that will have long-term value and widespread accessibility so that the rotorcraft community can increase their understanding of rotor behavior, refine and validate their analysis tools, and design improve rotorcraft. This supports NASA's goals for Capacity, Mobility and Technology Innovation

Accomplishments to Date

Completed a small-scale wind tunnel test in DNW and a full-scale flight test including maneuvers and acoustic. A large easy accessible database is maintained by NASA for use by industry and DOD. Several papers published and validation of prediction tools have been preformed. NRTC has used data to help improve prediction tools.

Future Plans / Opportunities

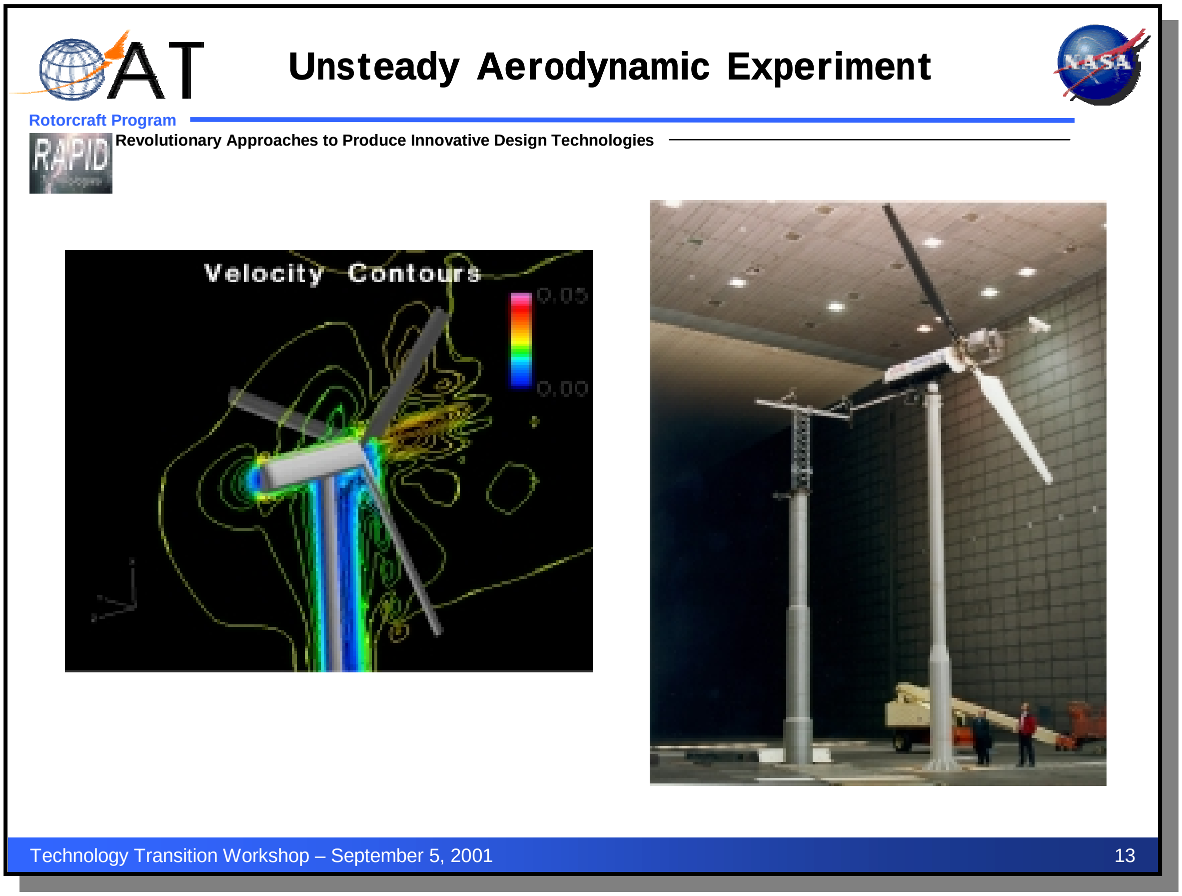
Maintain database and continue uses of data for validations. NRTC has initiated a new effort to improve the industry prediction codes using airload data for validation. Publish addition documentation. Collect wind tunnel measurements of the rotor airloads.

Partners

Army

POC

William Bousman, Ames Research Center (650) 604-3748, wbousman@mail.arc.nasa.gov



Goal

The goal of this project was to collect a complete set of aerodynamic loading information for a horizontal axis wind turbine over its full operating envelope using NASA Ames 80- x120-ft wind tunnel and a highly instrumented pressure blade. The wind turbine was also model using unsteady Reynolds averaged Navier-Stokes simulation (CFD calculation). The data will be used to validate current performance and loads predictions codes and the CFD models give insight to help develop aerodynamics models for rotor design codes). This work supports NASA's goal for Technology Innovation.

Accomplishments to Date

The test was completed in June 2000. CFD as well as comprehensive models were developed and exercised. Comparison to experimental results was made. A blind comparison with over ten different analyses was completed in November. Detail study of the stall delay is currently underway.

Future Plans / Opportunities

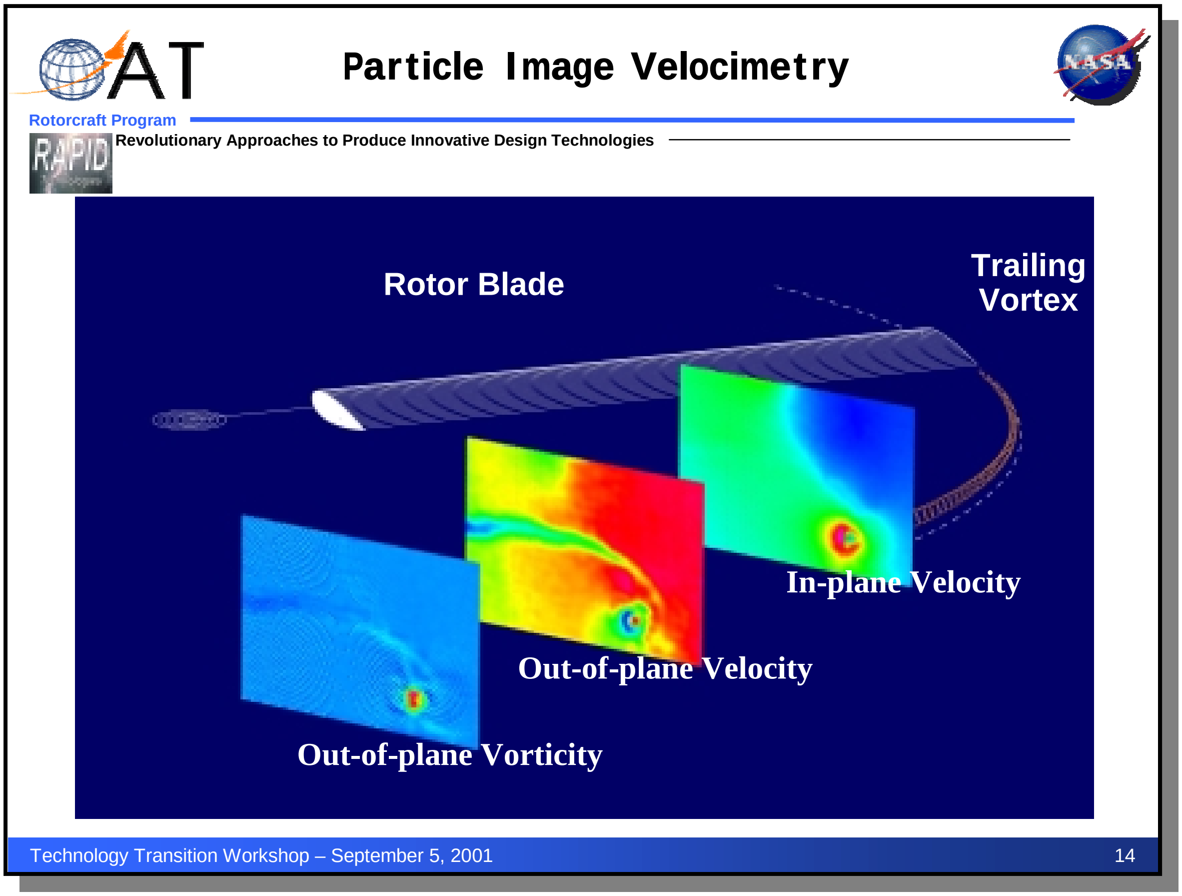
Continue stall delay study work with DOE and work with DOE to develop Aeroacoustic codes.

Partners

DOE

POC

Robert Kufeld, Ames Research Center, (650) 604-5664, rkufeld@mail.arc.nasa.gov



Goal
Develop a visualization tool to allow a rapid means for discovering the detailed structure of a vortex that trails from the tip of a hovering rotor. This tool will be used to validate complex rotorcraft wake theory, increase the understanding of vortex dynamic and allow a quantitative evaluation of various wake altering devices. This work supports NASA's goal for Technology Innovation.

Accomplishments to Date
Velocimetry measurements of tip vortex strength with various wake altering devices were made.

Future Plans / Opportunities
High resolution measurements in the near wake of main rotor blade will be used to develop and validate a theory designed to separately determine rotor thrust, profile drag and induce drag and define the aging and blade interaction on the structure of the vortex

Partners
Army

POC
Dr. Kenneth McAlister, Ames Research Center (650) 604-5892, kmcalister@mail.arc.nasa.gov

TRAM in 40- by 80-Foot Wind Tunnel

Rotorcraft Program

Revolutionary Approaches to Produce Innovative Design Technologies

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Goal

Develop and demonstrate a state-of-the-art tiltrotor test-bed. Acquire aeroacoustic database for validation of design tools required for tiltrotor noise reduction. This work supports NASA's goal for Noise reduction, Capacity, and Mobility.

Accomplishments to Date

Hover and forward flight wind tunnel testing was performed acquiring rotor blade structural loads, rotor and fuselage balance loads, and wing pressures, acoustics and flow visualization.

Future Plans / Opportunities

Continued development of model is planned and further testing will be performed in the 80-by 120-foot wind tunnel in late 2001. Advanced tiltrotor technologies and vehicle configurations will be validated/ demonstrated in the future using TRAM.

Partners

NASA SHCT Project

POC

Megan McCluer. Ames Research Center (650) 604-0010, mmccluer@mail.arc.nasa.gov

RAT
Rotorcraft Program
RAPID
Revolutionary Approaches to Produce Innovative Design Technologies

Full-Span TRAM
Adaptive Flow Control/Download Reduction

- 0.25 Scale V-22
- R = 4.75 ft (1.48 m)
- 3 Six-component balances
- 2 Electric drive motors, 300 HP each
- Bayonet mount, -9 to +18 degrees AOA
- Aeroelastically scaled rotors
- 150 Dynamic transducers in right-hand rotor
- 80-by 120-ft wind tunnel entry in FY 02

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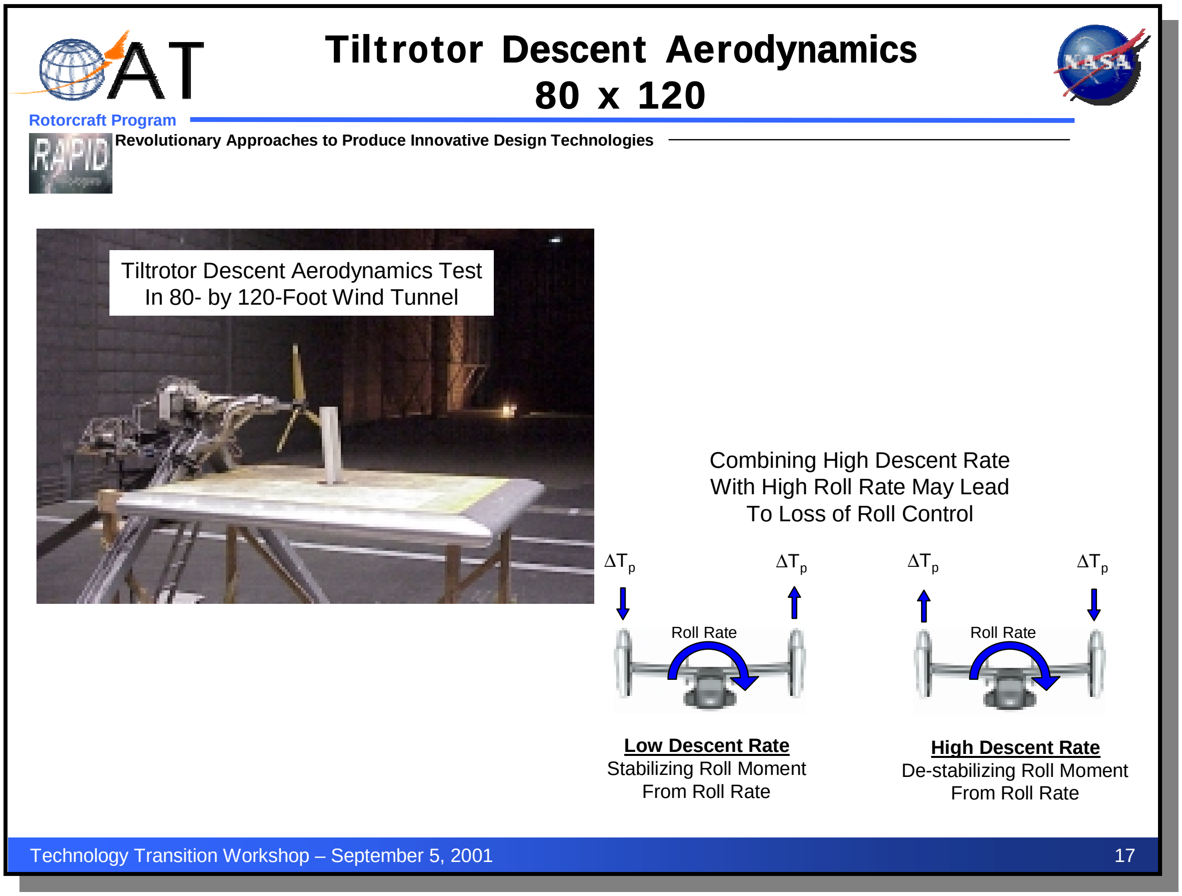
Goal
Use the TRAM with its advance instrumentation and modified with advance controls and flow actuators to reduce the down load during hover and low speed flight. The results should quantify power and flow requirements and help predict load reductions. This supports NASA's goals for Capacity, Mobility and Technology Innovation

Accomplishments to Date
After successful completion of the first Full-Span TRAM test the model is under-going modifications to prepare for the wind tunnel entry in FY 2002

Future Plans / Opportunities
Results from this effort could be used to improve performance of the V-22. TRAM will continue to be a testbed for tilt rotor research.

Partners
DARPA, Boeing

POC
Jeff Johnson, Ames Research Center, (650) 604-6976, jljohnson@mail.arc.nasa.gov



Goal

The goal was to develop accurate model to predict blade loading, including rotor interaction for tilt rotor at high descent rates. This work supports NASA's goal for Capacity and Mobility.

Accomplishments to Date

Completed a low-cost wind tunnel test of tiltrotor at high descent rates and documented flight conditions that put the rotor in a "vortex-ring-state". This is characterized by an unsteady rotor wake and oscillatory rotor thrust. Discovered that when high descent rate is combined with roll rate on a tiltrotor aircraft in helicopter mode, roll moment in the roll direction increases with roll rate, which could lead to loss of roll control

Future Plans / Opportunities

Communicate results to V-22 Integrated Test Team. Use acquired data to validate and improve analytical models. Conduct more wind tunnel experiments to better understand the implications of vortex-ring-state for tiltrotor aircraft.

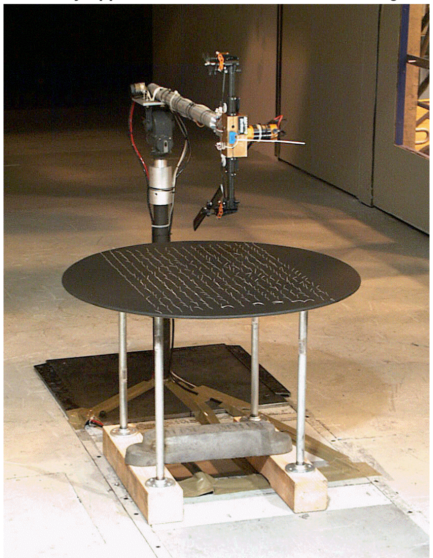
POC

Mark Betzina, Ames Research Center, (650) 604-5106, mbetzina@mail.arc.nasa.gov

Tiltrotor Descent Aerodynamics 7x10

Rotorcraft Program

Revolutionary Approaches to Produce Innovative Design Technologies



Isolated rotor with image plane

Tiltrotor model

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Goal

The goal was to develop accurate model to predict blade loading, including rotor interaction for tilt rotor at high descent rates. The use of small-scale models is investigated for the study of descent aerodynamics. If trends match previous testing of larger scale a more productive testing environment could be used. This work supports NASA's goal for Capacity and Mobility.

Accomplishments to Date

An experimental investigation was completed in the 7- by 10-Foot wind tunnel investigating a tiltrotor operating in descent and sideslip conditions. Results show that this small scale model capture the necessary physics to investigate the aerodynamics of interest.

Future Plans / Opportunities

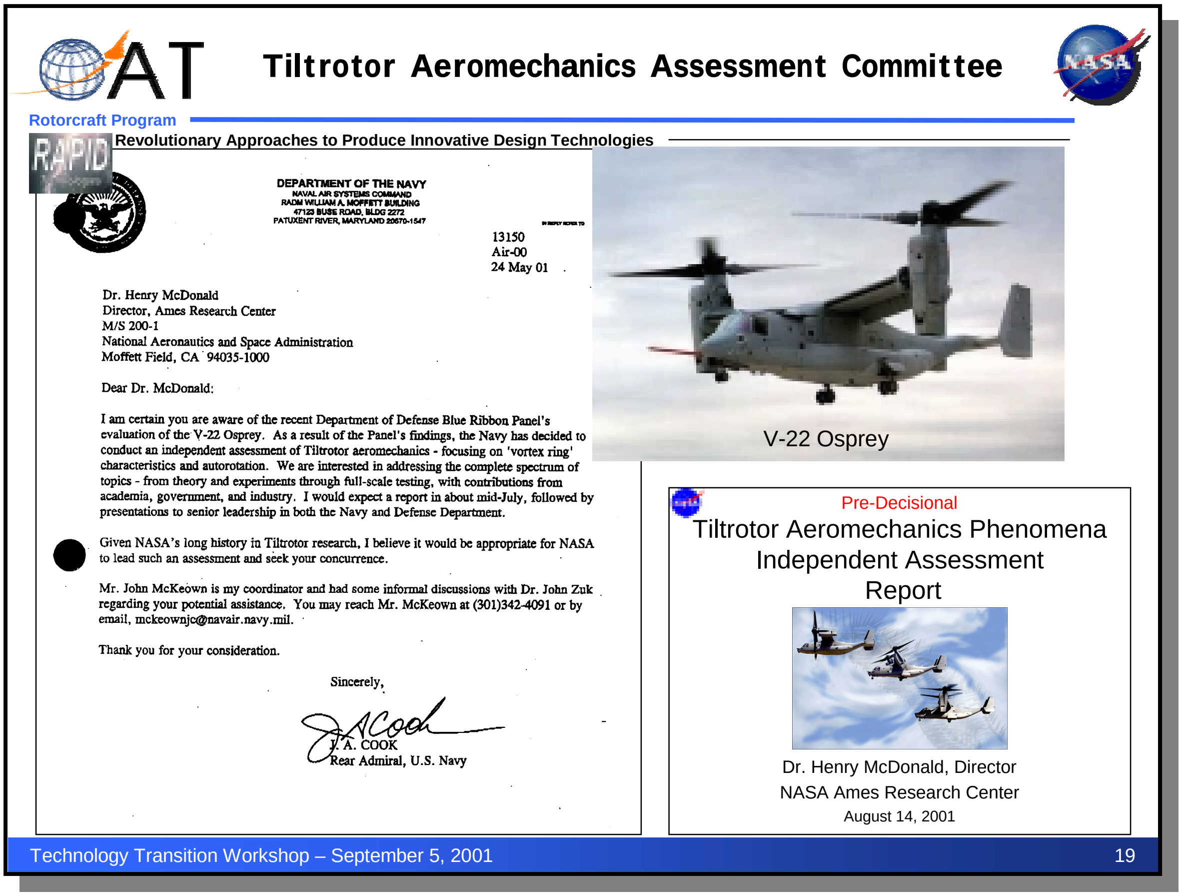
Document results of wind tunnel investigation. Conduct a follow-on test program that will provide higher fidelity information on the ability to model full-span behavior with a single rotor operating in the presence of an image plane. Provide results to U.S. Navy V-22 program to understand fundamental behavior of tiltrotor aircraft in high-speed descent

Partners

Navy

POC

Anita Abrego, Ames Research Center, (650) 604-2565, aabrego@mail.arc.nasa.gov



Goal

To develop a comprehensive assessment and summary of Tiltrotor Aeromechanics Phenomena (vortex ring state, autorotation, low speed maneuvering, etc.) that could be encountered by tiltrotor aircraft. This activity supports NASA's goal for Capacity and Mobility.

Accomplishments to Date

The Naval Air Systems Command requested that NASA lead an "independent assessment of Tiltrotor aeromechanics - focusing on 'vortex ring' characteristics and autorotation." In response to the Navy's request, a committee was established, including both a Technical Team and a Panel to assess the present understanding of tiltrotor aeromechanical phenomena. The Technical Team was led by Ames personnel and included representatives from government, academia, industry and the military. The Panel was chaired by Dr. McDonald and consisted of non-affiliated senior rotorcraft aeromechanics experts. Meeting were held during the summer and the Panel developed finding and recommendation for their final report. Dr. McDonald gave a pre-decisional briefing to Under Secretary of Navy's Office, the Secretary of the Air Force, and the Under Secretary of Defense for Technology and Acquisition in August.

Future Plans / Opportunities

The final written report is due mid-September with a full briefing to the V-22 Program Executive Committee.

Partners

Army, Navy, Air Force, Bell, Boeing

POC

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Rotorcraft Program

SILNT- Select Integrated Low Noise Technologies

Active Noise Controller Development

XV-15 Rotor in 80- by 120-Foot Wind Tunnel

Technology Transition Workshop – September 5, 2001 20

Goal

Develop and test a controller to reduce rotorcraft blade-vortex interaction (BVI) noise. This work supports NASA’s goal for Noise reduction.

Accomplishments to Date

Demonstrated successful BVI noise reduction using microphone and blade-mounted pressure feedback along with a dedicated signal processing technique for noise detection using higher harmonic control on an XV-15 rotor in the 80x120 wind tunnel.

Future Plans / Opportunities

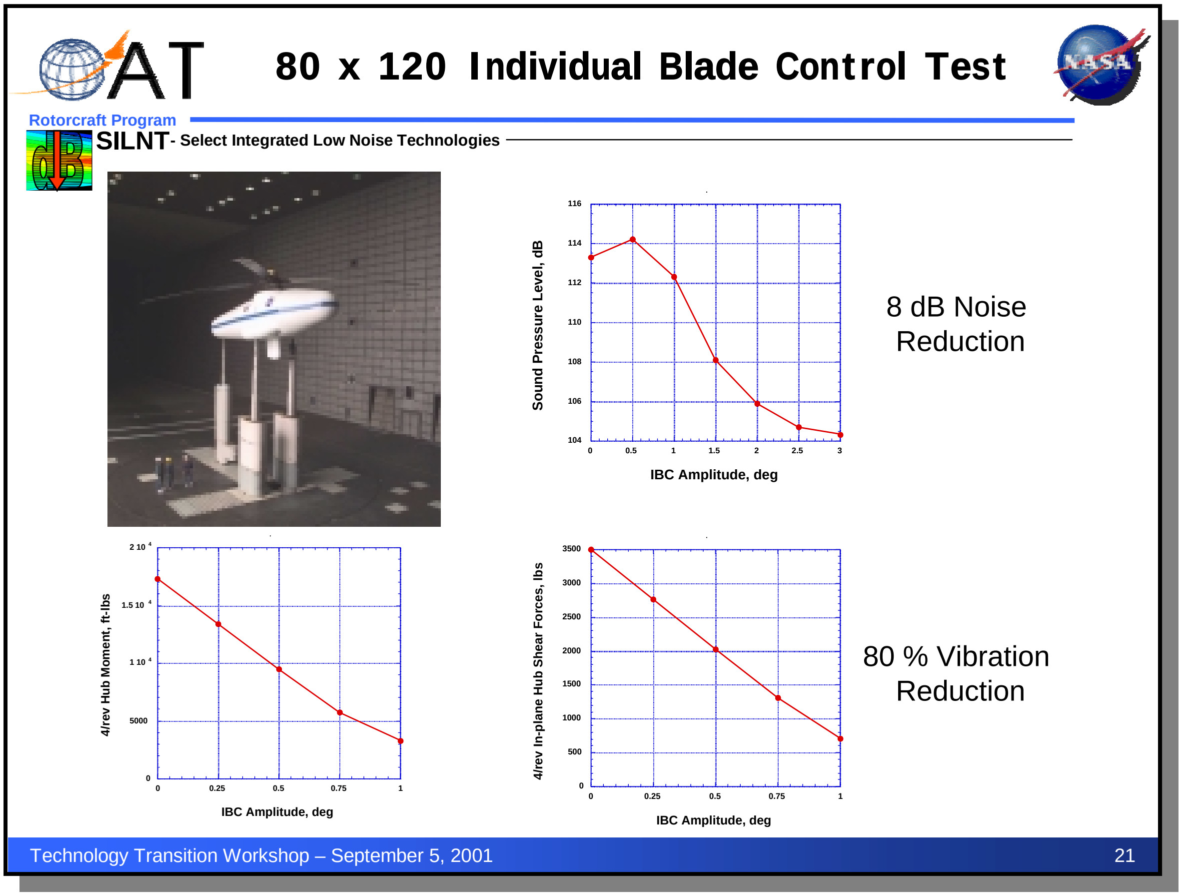
Refine and test controller algorithms for the upcoming individual-blade-control test of the full-scale UH-60 Rotor in the 40- by 80-Foot Wind Tunnel.

Partners

NASA SHCT Project

POC

Khanh Nguyen, Ames Research Center, (650) 604-5043, knguyen@mail.arc.nasa.gov



Goal

The goal of the individual blade control (IBC) system research is to develop the IBC technologies to the point where their effectiveness can be successfully demonstrated in-flight on a production military or civilian helicopter. It is anticipated that IBC will provide very effective rotor system noise suppression, together with substantial reductions in helicopter vibration and increases in rotor performance. This supports NASA's goals for Noise, and Technology Innovation

Accomplishments to Date

The IBC system has been installed, checked out and operated on the LRTA within NASA Ames Research Center's 80x120-ft wind tunnel. Data has been collected for hover and forward flight. The data collected so far have shown 80% reduction in vibration and 8db reduction in noise.

Future Plans / Opportunities

Plan include the completion of current 80x120 test with a follow-on high speed test in 40x80 using current test rig and a set of wide chord UH-60 blades. It is believed vibration reduction of 90% and 12db reduction of BVI noise will be seen. Advance control laws will be investigated. Operation specification such as input amplitude, hydraulic flow rates and power requirements will be determined for moving the IBC system to flight.

Partners

Army, Sikorsky, ZFL

POC

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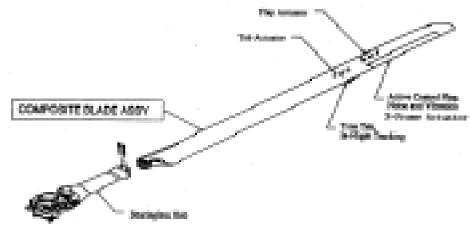
SMART Rotor Development

Rotorcraft Program

SILNT - Select Integrated Low Noise Technologies

Wind Tunnel Test of Full-Scale Smart MD-900 Rotor



Key Components of Smart MD-900 blade

Technology Transition Workshop – September 5, 2001 22

Goal

Demonstrate application of smart materials to rotorcraft through full-scale wind tunnel and flight tests of MD-900 rotor system This supports NASA's goals for Noise, Technology Innovation, and Capacity.

Accomplishments to Date

Demonstrated in a model flap authority sufficient to achieve major aeroelastic benefits. Built and bench tested a full-scale MD-900 smart blade equipped with piezoelectric actuated trailing edge flap. Flight hardware development is 50% complete.

Future Plans / Opportunities

Test the MD-900 Smart rotor in whirl tower Nov. 01,flight test 2nd quarter 02 and in the 40- x 80-Foot Wind Tunnel by the end of FY 02.

Partners

DARPA, Boeing

POC

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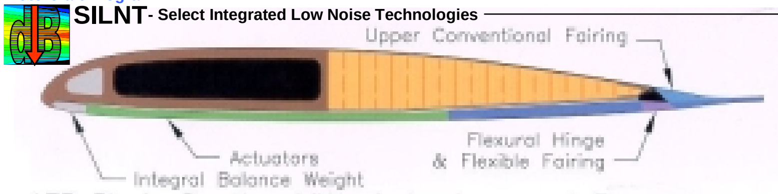
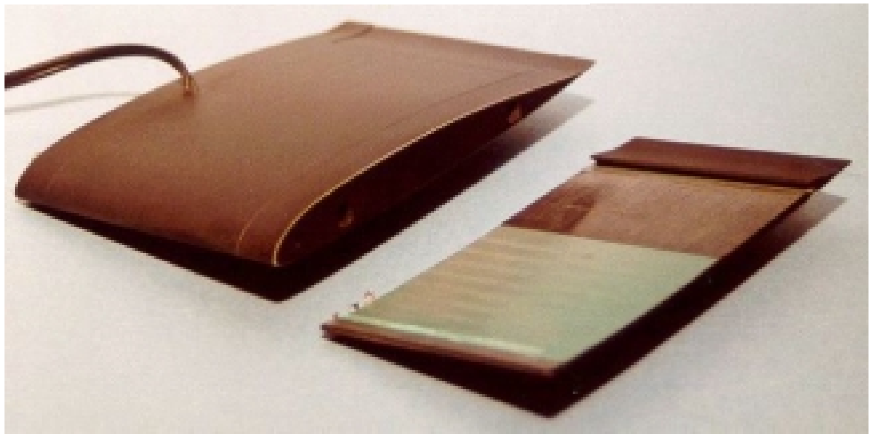
Active Elevon Rotor (AER) Technology for Low Vibration

Rotorcraft Program

SILNT- Select Integrated Low Noise Technologies



AER Blade Section With Actuators and Elevon



Developed by Domzalski Machine under SBIR DAAH10-99-C-0022.

Technology Transition Workshop – September 5, 2001 23

Goal

The goal of the Active Elevon research is to develop the technologies and evaluate their performance within an operational environment. It is anticipated that the active elevon will provide very effective rotor system noise suppression, together with substantial reductions in helicopter vibration and increases in rotor performance. This supports NASA's goals for Noise, Technology Innovation and Capacity.

Accomplishments to Date

Blade preliminary design 25% complete. Rotor diameter is 13 ft., chord 5.67 in., with 15% elevon chord and 0.60 tip Mach No. The elevon will use the Conformal Actuator Technology, developed by Domzalski Machine. Two-dimension Computational Fluid Dynamics calculation have been performed by UC Davis.

Future Plans / Opportunities

Complete blade design and fabrication and proof testing. Perform an airfoil test at DLR. Finish test stand build-up and checkout including new hub, swashplate, gears, instrumentation and slip ring. Prepare for 40-x80-ft test in late 20 02.

Partners

Army

POC

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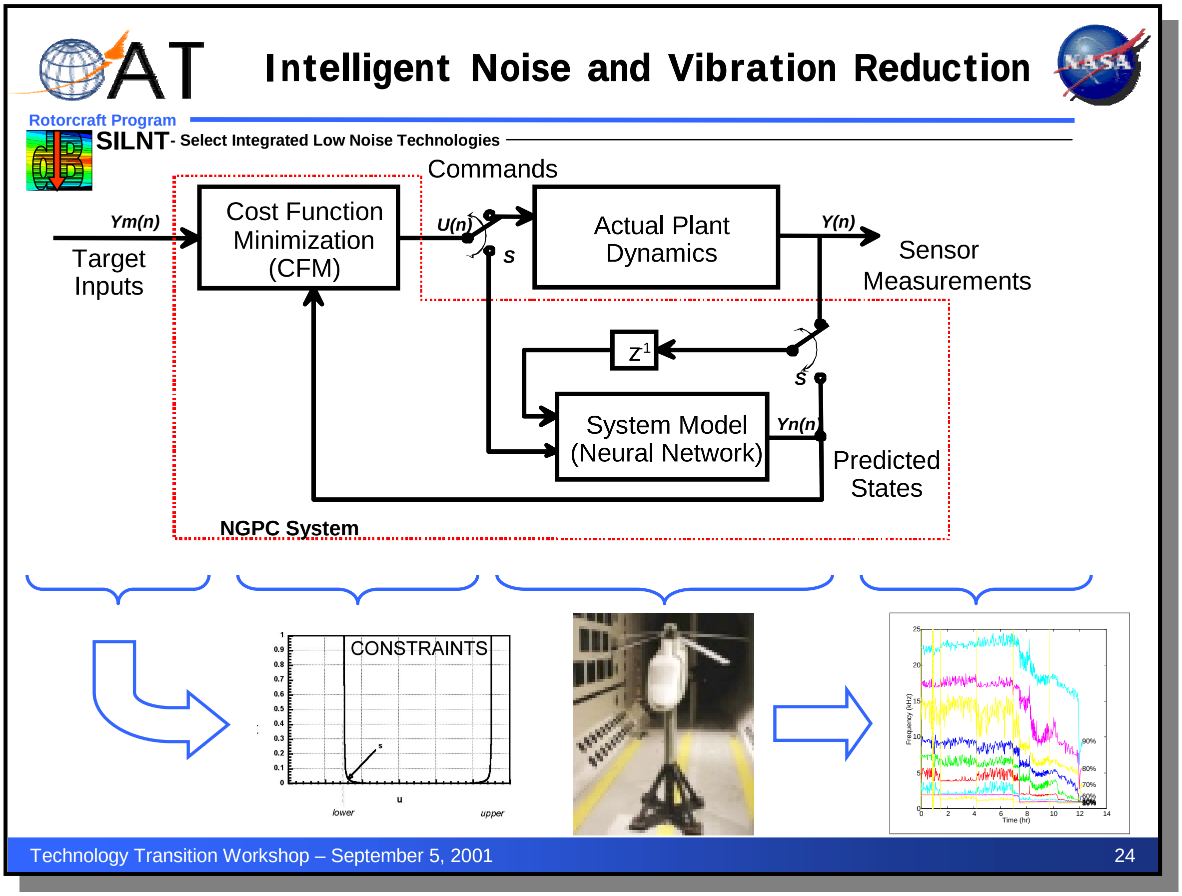

Goal

The goal of this project is to develop a noise and vibration controller for rotorcraft using enhanced neural network algorithms and adaptive control technologies for noise and vibration minimization. . This supports NASA's goals for Noise, Capacity, Mobility, and Technology Innovation

Accomplishments to Date

The Research Plan was approved May 1, 2001 for 1QFY02 testing in Langley Research Center TDT wind tunnel. FY01 funding received and part time contract staff hired to support code development. Dedicated software licenses purchased to support software development. Control system development and NNET software modifications currently underway to re-host Neural Generalized Predictive Control.

Future Plans / Opportunities

Develop notch filtering on cost function, examine both frequency and/or time domain NGPC implementations using simplified system models. Testing slipped to late 02

POC

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Rotorcraft Program

RAPID Status Summary

Tasks	Funding Source	Status	Continuation actions
Advanced Configuration			
1. Advance Runway Independent Aircraft Concepts	NASA	Near Complete/future work in doubt	
2. Parametric cost models	NASA	On-going/future work in doubt	
3. Variable Diameter Tilt Rotor (VDTR) Demonstrator	REVCON	Phase I complete/future work in doubt	
4. Swashplateless Flight Demonstrator	REVCON	Phase I complete/future work in doubt	
5. Ducted Fan Investigation	NASA/DARPA	Complete	
Computational Code Development			
1. Computation Modeling of Rotorcraft Aerodynamics	ARMY/NASA	On-going/Army should continue	
2. Computation Modeling and Validation of Hovering Rotor Aerodynamics	Army/NASA	On-going	
3. Real Time Rotorcraft Free Wake Modeling	SBIR	Complete	
4. UH-60 Airloads	NASA/ARMY	Phase I & II compete/future work in doubt	
6. Unsteady Aero	DOE/ NASA	Complete	
5. Applied Particle Image Velocimetry	NASA/Army	Complete	
Tilt Rotor Aerodynamic/Acoustic			
1. Full-Span Tilt Rotor Aeroacoustic Model	SHCT/Base/Army	Phase I & II complete/future work in doubt	
2. V-22 adaptive flow control	DARPA/Boeing	Future work in doubt	
3. Tilt Rotor Descent Aerodynamic 80x120	NASA	Phase I complete	
4. Tilt Rotor Descent Aerodynamic 7x10	NASA/Navy	Phase I complete/Navy funding in FY02	
5. Tilt Rotor Aerodynamic Assessment Committee	NASA/Navy	Complete	
Noise & Vibration control			
1. Active Noise controller XV-15	SHCT/BASE	Complete	
2. UH-60 IBC	NASA/Sikorsky/ZFL	On-going/future work in doubt	
3. Smart	NRTC/DRAPA/Boeing	On-going/future work in doubt	
4. Active Elevon Rotor	Army/NASA	On going/future work in doubt	
5. Intelligent Noise and Vibration Reduction /Neural Generalized Predictive Contro	NASA	Near Complete	

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NASA Langley Tasks

Rotorcraft Program

SILNT

RAPID

Select Integrated Low Noise Technologies (SILNT)

and

Revolutionary Approaches to Produce Innovative Designs (RAPID)

Michael E. Watts

Langley Rotorcraft Program Manager

Rotorcraft Program

SILNT

SILNT Project Overview

Project Goal

Develop the technology to reduce rotorcraft interior and exterior noise, consistent with NASA Goals: Reduce the perceived noise of future aircraft by a factor of two by 2007 and by a factor of four by 2022. Double the aviation system capacity by 2007 and triple it by 2022.

Objectives

1. Develop low-noise drive systems
2. Develop low-noise & vibration rotor systems
3. Develop low-noise operations

Benefit

Rotorcraft to meet community and passenger acceptance standards for environmental noise and ride quality.

Partners

Bell, Boeing, Sikorsky, US Army, DARPA, FAA

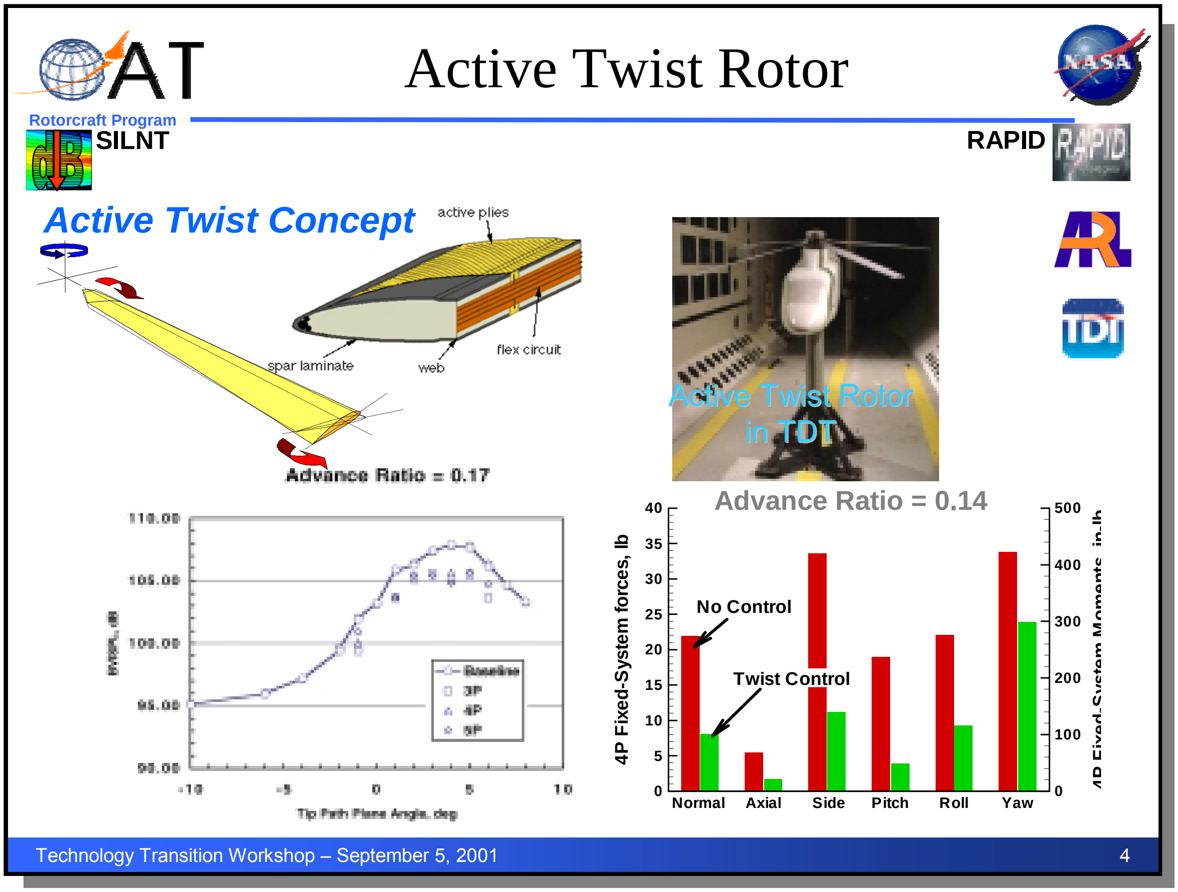
Technologies/Tasks Presented

Rotorcraft Program

SILNT

RAPID

- RAPID
  - Active Twist Rotor (ATR, Joint with SILNT)
  - Projection Moire Interferiometry (PMI)
  - Wing Rotor Aeroelastic Testing System (WRATS)
  - Stringer Pull-off Prediction
- SILNT
  - Low Noise Planform
  - Modulated Blade Spacing
  - Development of Noise Abatement Procedures
  - TiltRotor Aeroacoustic Code (TRAC)
  - Rotorcraft Aeroacoustic System Prediction (RASP)
  - Advanced Rotor Aeroacoustic Modeling (ARAM)
  - Rotorcraft Noise Model (RNM)
  - DGPS Tracking and Guidance System
  - HART II Test



Active Twist Rotor Control for Noise and Vibration Reduction
Matt Wilbur, Earl R. Booth, Larry Becker, Paul Mirick, Bill Yeager, and Chester Langston

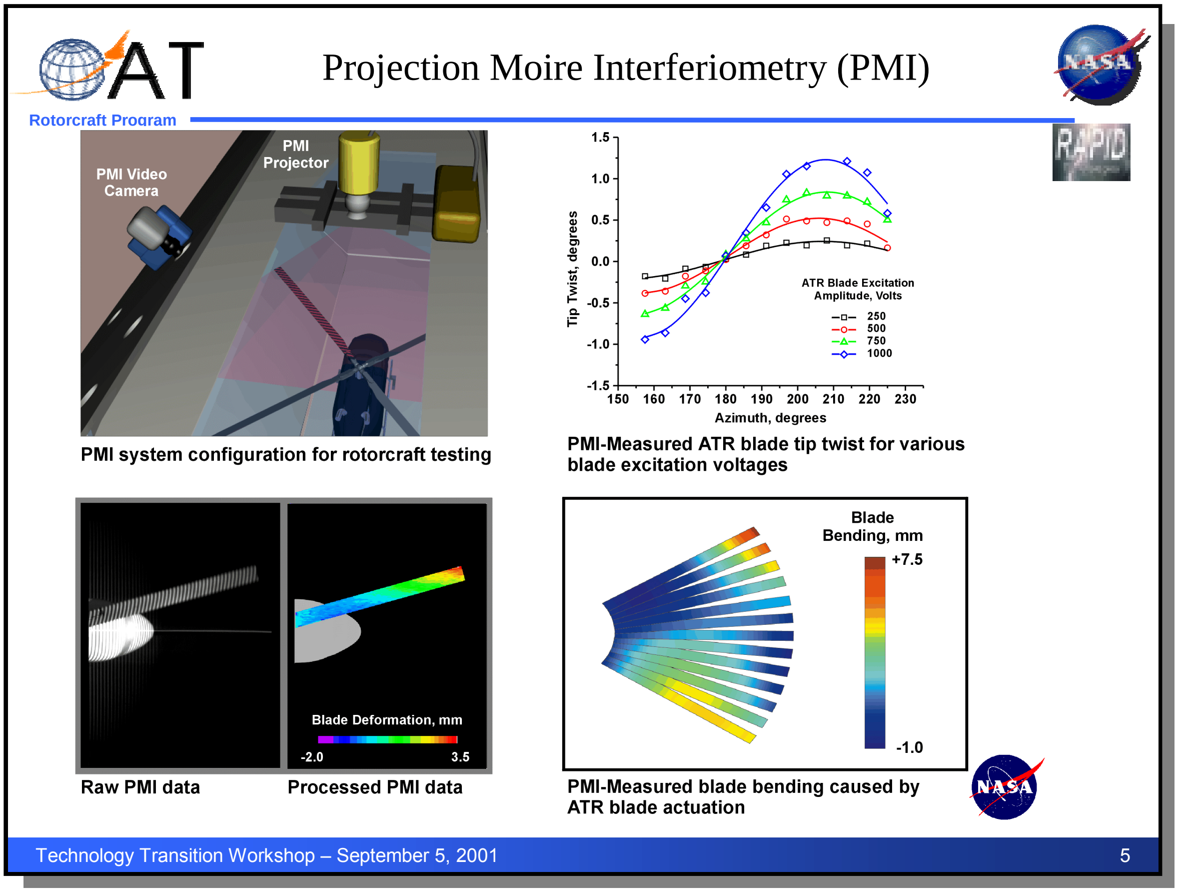
Relevant Milestone: Assess the feasibility of multiple radical rotor noise and vibration reduction concepts. (SILNT #2 due Sep 00)

Shown: Active Twist Rotor concept. Blades installed in the Transonics Dynamics Tunnel. Test results for simultaneous fixed-system load reduction obtained using active twist control for a typical 1g forward flight case at an advance ratio of 0.14 and shaft angle-of-attack of –1 degree. A comparison of BVI noise levels at advance ratio = 0.17 with and without ATR as a function of tip path plane angle is also shown.

Accomplishment/Relationship to Milestone and ETO:
- New method for rotor noise and vibration reduction using active twist blade control. Contributes to milestone completion.
- Active blade twist was imposed on a rectangular planform, NACA 0012, linear twist blade set. Resulting changes in rotor performance, vibration and acoustic characteristics were compared with the baseline blade (no active twist) case, in a four-week test in the TDT.
- Using an open-loop control system, vibration reductions of 60% to 100% have been demonstrated for all 4P fixed-system load components with exception of yawing moment. General trend suggests that simultaneous reduction of most fixed-system loads, regardless of flight condition, is possible.
- Noise reduction in conditions dominated by Blade-Vortex Interaction (BVI) noise was comparable to noise reduction provided by Higher Harmonic Control (HHC). As shown, in the region of highest BVI noise levels for this advance ratio, ATR reduced the noise up to about 3 dB.
- On July 18 and 19, Matt Wilbur, an Army employee in the Aeroelasticity Branch, traveled with Mr. Dan Hoad, Chief of the Army Loads and Dynamics Division at Langley, to *Sikorsky Aircraft* in Stratford, CT, to discuss the results of last year's Active Twist Rotor test in the Transonic Dynamics Tunnel. Approximately 15 Sikorsky engineers attended the briefing, which was well-received and generated numerous discussions and comments regarding the potential for active twist rotor systems to minimize vibratory loads in rotorcraft.
- A follow-on trip was made on July 23 to present the material to *Boeing Helicopters* in Philadelphia, PA. A similar, positive reaction was displayed by Boeing.

Future Plans/Opportunities:
- It is intended to test the existing ATR blade set using three closed loop control systems in FY02. These algorithms include testin a Clasic closed loop controller, Generalized predictive controller and Neural generalized predictive controller.
- Extensions of this research would be to build the blade set using MFC actuators to increase control authority and retest with the closed loop controllers. Additional trips are being planned to present the results to *Bell Helicopter* and *Boeing-Mesa*, and other Army organizations at NASA Ames Research Center and Huntsville, AL.

POC: Matt Wilbur,Langley Research Center, (757) 864-1268, m.l.wilbur@larc.nasa.gov



Projection Moire Interferometry (PMI) for Blade Deformation Measurements during Active Twist Rotor (ATR) Testing
Gary Fleming, Hector Soto, and Bruce South

Relevant Milestone: DEAR 5: Rotor/Wake Load Model, accurate model to predict blade loading, including rotor wake interaction, rotor maneuver neat limits of rotor envelope.

Shown: A schematic of the PMI system configuration for rotorcraft testing is shown along with PMI-measured blade deformation data acquired during the ATR test. The images show full-field raw and processed PMI data for a single blade at 195 degrees azimuth. Additional plots showing spanwise blade bending and azimuthally-dependent tip twist are provided.

Accomplishment/Relationship to Milestone and Goal:

- A significant component of this DEAR milestone is the development of advanced test techniques for blade deflections. PMI is a non-contacting optical technique for measuring structural deformation which can be applied to rotorcraft testing.
- The PMI technique as developed under DEAR was applied to the SILNT ATR test conducted in the LaRC Transonic Dynamics Tunnel to provide (a) blade deformation data to ATR researchers, and (b) additional development opportunities for the PMI technique.
- PMI was used to obtain full-field ATR blade deformation measurements over the 160 - 220 degree azimuth range for numerous blade actuation and flight conditions.
- The full-field PMI measurements have been reduced to provide azimuthally-dependent spanwise blade bending, twist, and tip twist data

Plans: The PMI technique will continue to be developed for rotorcraft blade deformation measurements.

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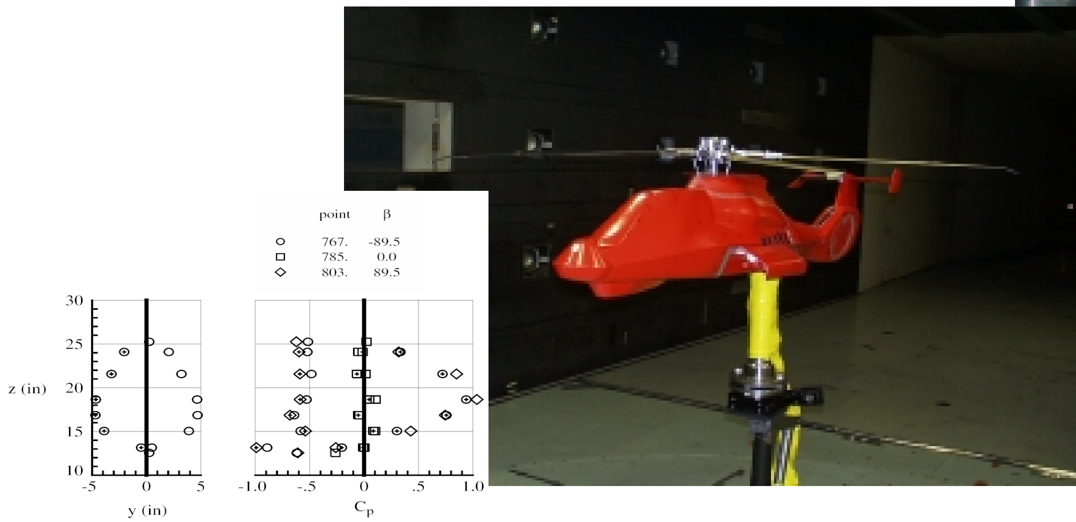
Interactional Aerodynamics

Rotorcraft Program

RAPID



Comanche Lateral Pressure Distribution at X=17 in.
Port side is centered symbol

Technology Transition Workshop – September 5, 2001 6

Interactional Aerodynamics
Kevin Noonan

Relevant Milestone: Rotor/Airframe Interaction Model (RAPID #3 due Jul 03)

Shown: 1) 15%-scale Comanche model in the 14x22-Foot Subsonic Wind Tunnel tested in FY01. 2) Static pressure distributions at one fuselage cross section (longitudinal station=17 in.) at high sideslip angles without the presence of the rotor flow.

Accomplishment / Relationship to Milestone and ETO:

- Extensive fuselage static pressure measurements were made on the 15%-scale Comanche model during the FY01 entry in the Langley 14x22-Foot Subsonic Wind Tunnel.
- This work is essential to understand and model the complicated flow field around a helicopter. This research will enable rapid design and evaluation of innovative vertical lift configurations for the next generation public transportation systems.

Future Plans: Plans are to make extensive measurements of the static pressures on the Comanche fuselage in the presence of the flow field of the Comanche anhedral tip rotor. DGV measurements will be added to the test instrumentation suite for the next test planned in FY02.

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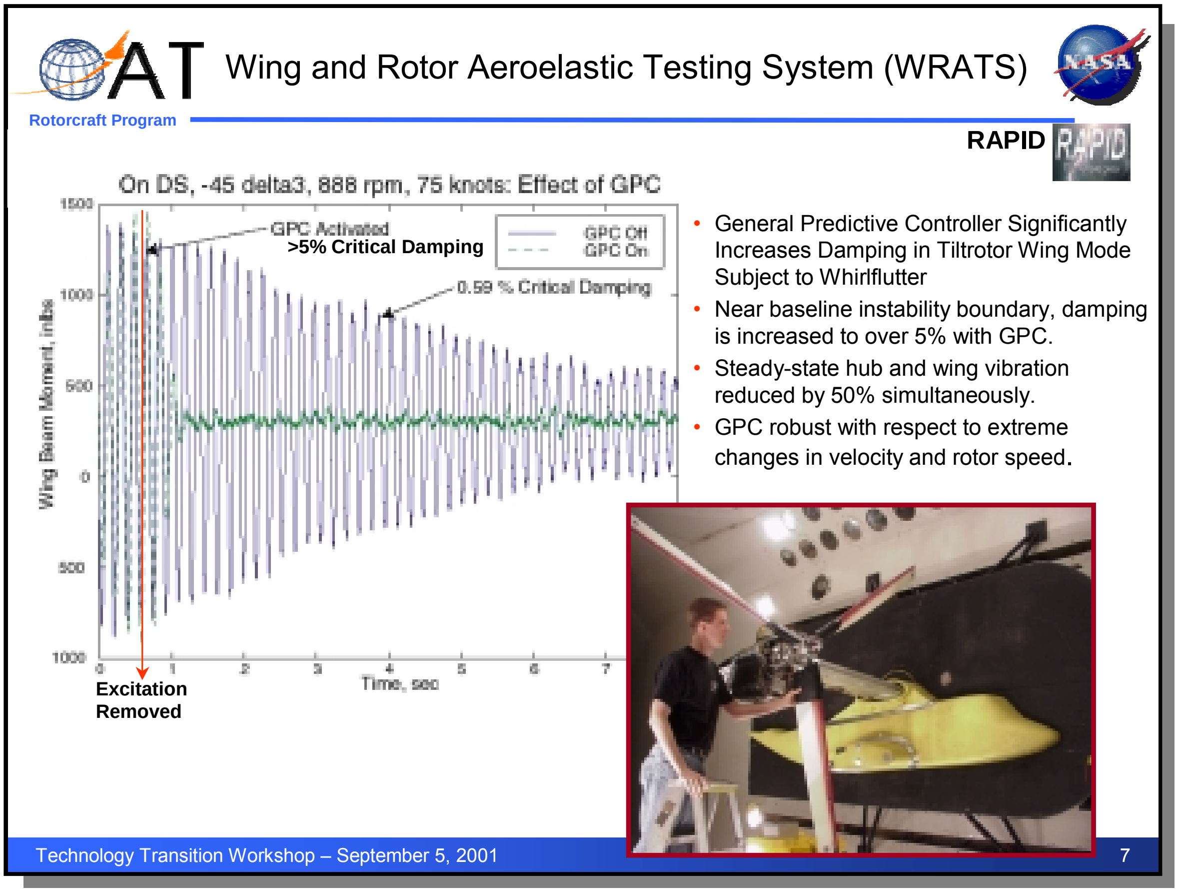

STABILITY BOUNDARIES ESTABLISHED FOR BASELINE CONFIGURATION OF WRATS TILTROTOR MODEL
Mark W. Nixon

Objective: The objective of this test was to evaluate the stability characteristics of the baseline Wing and Rotor Aeroelastic Testing System (WRATS) tiltrotor model.

Approach: WRATS, a semispan testbed developed from the former V-22 1/5-scale aeroelastic tiltrotor model, was designed and fabricated by BHTI. The baseline model is currently on loan from the Navy to the NASA LaRC and is maintained by the LaRC Aeroelasticity Branch which operates the Transonic Dynamic Tunnel (TDT). Based on the use of the WRATS model, an aggressive test program was developed to address tiltrotor aeroelastic research issues as identified by: 1) the NASA Short-Haul Civil Tiltrotor (SH-CT) Program; 2) U.S. rotorcraft industry with regard to the development of marketable tiltrotor technologies; and 3) the U.S. Army with regard to the development of high-speed rotorcraft capabilities. A key to improving marketability of current tiltrotor systems is to reduce noise and weight and to improve aerodynamic performance. Such reductions and improvements generally result in an associated detrimental impact on the loads, vibration, and aeroelastic stability of the vehicle. One opportunity for improving aerodynamic performance in the airplane flight mode is to reduce the wing thickness to chord ratio (t/c). The current V-22 wing thickness (23% t/c) is necessary to provide the stiffnesses required to avoid proprotor whirl flutter at high speeds. A new wing design has been developed with structural characteristics tailored using composite materials such that a thinner wing (18% t/c) will have stability characteristics equal to or better than the current thicker wing. The thick wing design is accurately represented by the current baseline WRATS tiltrotor model while the thin wing design has been fabricated by BHTI as a modification for the WRATS model.

Accomplishments: During a recent test of the WRATS baseline model in the airplane mode (photo on figure) a significant amount of high-quality data was obtained. The plots presented on the right side of the figure represent proprotor whirl flutter boundaries for each of two wing torsion frequencies (altered by replacement of a pylon/wing connection spring). Each frequency corresponds to a different configuration of the full-scale pylon/wing downstop-lock mechanism. The boundaries are presented as rotor speed as a function of airspeed. As the plots show, a difference in wing torsion frequency of only 0.2 Hertz produced a shift in the flutter boundary of about 30 rpm at constant airspeed, or equivalently, a shift of about 12 knots at constant rpm. Subcritical damping data (not shown) of the wing modes as a function of airspeed for each of the two design rpm's was also obtained during the test.

Significance: The baseline stability data is of fundamental importance for demonstrating acceptable stability margins of a thin composite wing design which has been developed based on analytical stability predictions. The airspeed/rpm stability boundary data from this test will be used in conjunction with data developed from a planned composite tailored wing test to determine if the current analytical design is suitable for flight testing. The subcritical damping data will be used to compare with and refine analytical predictions.

Plans: The composite tailored wing modification to the baseline tiltrotor model is to be tested in the next WRATS entry. The WRATS has been repaired and will be operational in late CY01.

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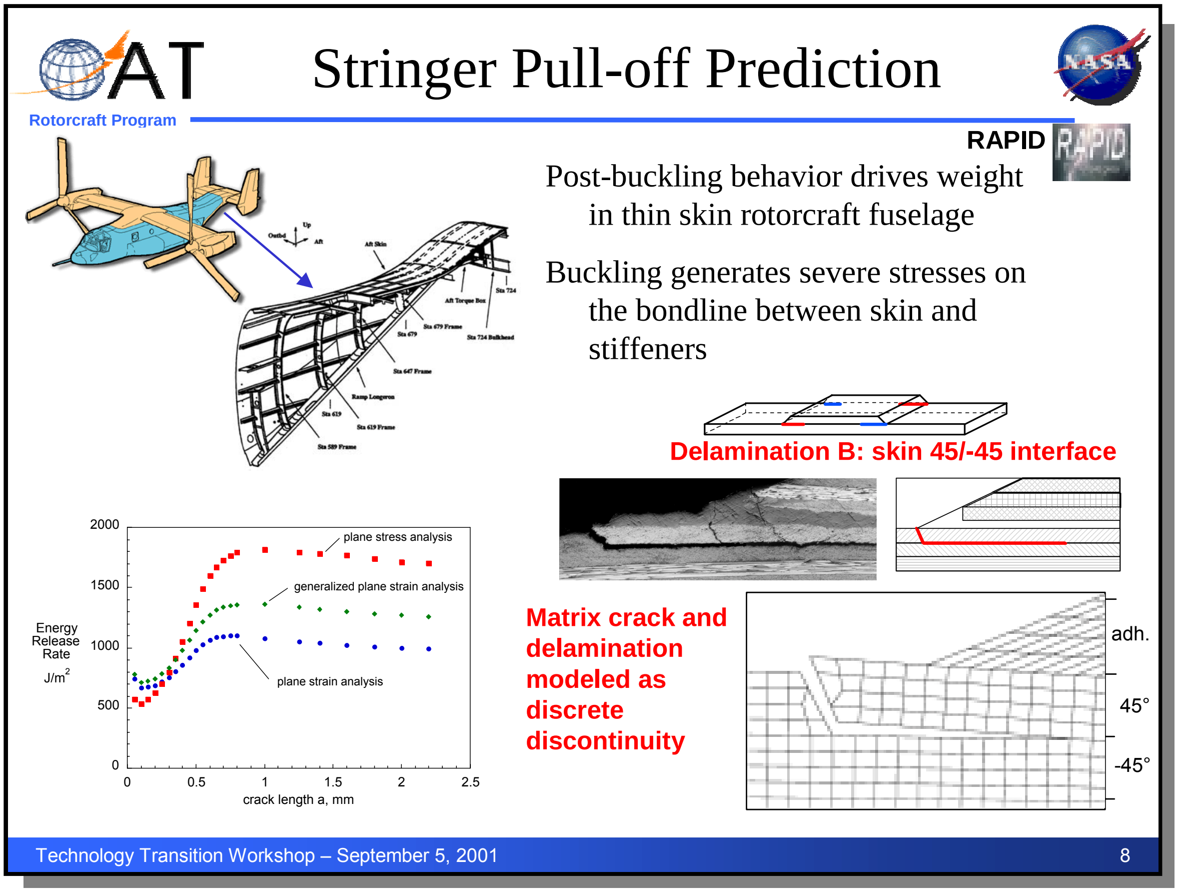

Composite Stringer Pull-off Failure Prediction
Dr. T. Kevin O'Brien

Relevant Milestone: Establish experimental and analytical methodology for composite stringer pull-off failure prediction. (RAPID Level 1 Milestone, due 4th Qtr FY01)

Shown: Computed energy release rates for delamination growing in top skin ply interface using different 2D assumptions

Accomplishments

- Rotorcraft fuselage consist of very thin composite skins reinforced with adhesive bonded stringers. Unlike fixed wing fuselage structure, these thin rotorcraft fuselage skins are allowed to buckle under repeated loading, resulting in a separation of the reinforcing stringers from the fuselage due to a combination of matrix cracking and delamination in the skin or stiffener flange.
- Two-dimensional (2D) finite element analyses of tension and bending specimens were performed substituting the standard 2D plane stress and 2D plane strain elements in the model along with a special 2D generalized plane strain element. Generalized plane strain elements are typically used to model a section of a long structure that is free to expand axially or is subjected to axial loading. Current models included matrix cracks and delaminations as observed in the static skin/flange tension and bending tests.
- Computed energy release rates were compared for all three types of 2D elements. As shown in the figure, results obtained from the generalized plane strain model fall between the upper and lower limits from the 2D plane stress and 2D plane strain elements. However, the different types of elements may yield results that differ by as much as 40%. Because 3D models are too large and slow for use in design studies, a 2D approach is desired. However, In order to determine which 2D assumption is most accurate for these types of problems, 3D models are needed.

Future Plans: A 3D finite element analysis will be developed to predict the damage observed in these skin/stringer pull-off specimens typical of rotorcraft fuselage constructions and determine the most accurate 2D approach for design trade off studies.

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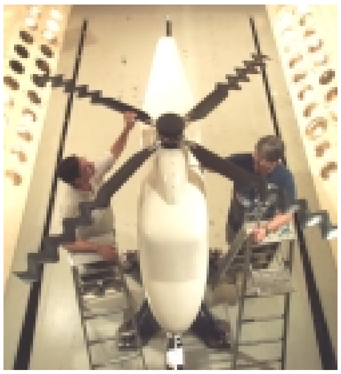
Low Noise Planform

Rotorcraft Program

SILNT

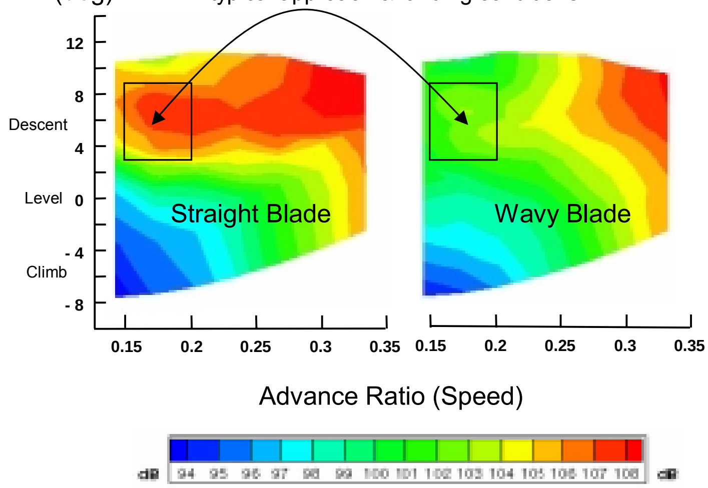
Wavy Planform Rotor Reduces Noise by 4 to 10 db!



Wavy Planform Rotor in Langley Transonic Dynamics Wind Tunnel

Noise Reduction

significant noise reduction (≈ 4 to 10 dB) for typical approach & landing conditions.



Low Noise Planform
Thomas F. Brooks and Earl R. Booth

Relevant Milestone: Low Noise Rotor (SILNT #2 due Sep 00)

Shown: Wavy planform rotor. Noise levels of wavy rotor noise compared to baseline (straight) rotor.

Accomplishment / Relationship to Milestone and ETO:

- The Wavy Planform Rotor (Patent Disclosure LAR16084-1, Brooks**)** was tested and compared with a rectangular planform, NACA 0012, linear twist blade set. This test completes the program milestone and is a major step toward the goal of the SILNT project to demonstrate new methods of rotor noise reduction.
- Acoustic measurements in the hard-walled reverberant wind tunnel test section employed sound power measurement techniques calibrated to determine noise levels but not noise directivity. Significant noise reductions of 4 to 10 dB were found for conditions dominated by blade-vortex interaction (BVI) noise, which is the biggest source of noise during approach and landing of helicopters. Beneficial noise reductions were also found in low and high frequency ranges which are significant in other flight regimes.
- This technology is a major step in providing community-friendly rotorcraft.

Future Plans: Continue data analysis is required to completely define the performance benefits. Technology will be transferred to industry, with proposal for cooperative agreement to refine rotor-blade design followed by testing.

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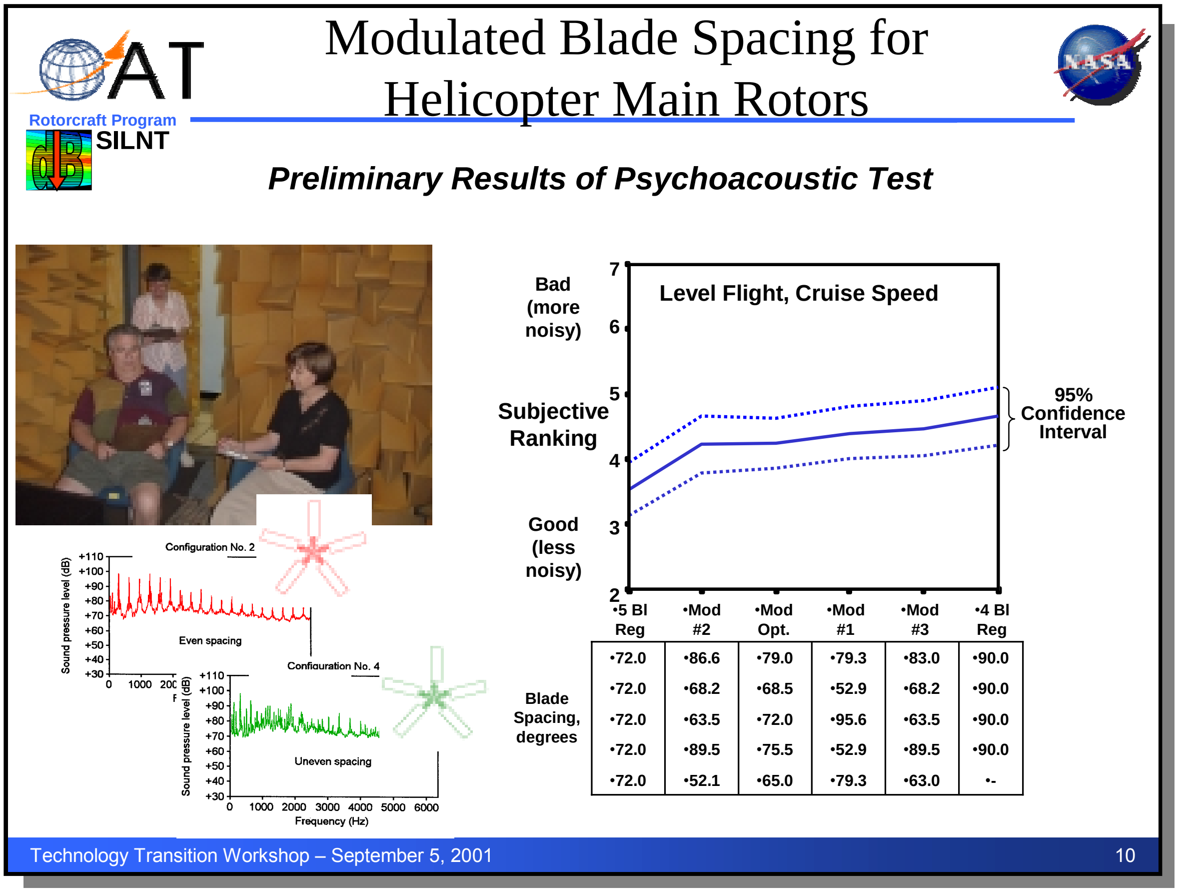

•5 Bl Reg	•Mod #2	•Mod Opt.	•Mod #1	•Mod #3	•4 Bl Reg
•72.0	•86.6	•79.0	•79.3	•83.0	•90.0
•72.0	•68.2	•68.5	•52.9	•68.2	•90.0
•72.0	•63.5	•72.0	•95.6	•63.5	•90.0
•72.0	•89.5	•75.5	•52.9	•89.5	•90.0
•72.0	•52.1	•65.0	•79.3	•63.0	•-

Modulated Blade Spacing for Helicopter Main Rotors Preliminary Results of Psychoacoustic Test
Brenda Sullivan, Bryan Edwards, and Earl R. Booth

Relevant Milestone: Assess the feasibility of multiple radical rotor noise & vibration reduction concepts.

Shown: Photograph of subjects in psychoacoustic testing facility, a sketch of the modulated blade concepts and the effect uneven blade spacing on rotor spectra, and a plot of the subjective rating for the six configurations tested.

Accomplishment/Relationship to Milestone and ETG:

- A subjective test was conducted June 18-26 at the NASA-Langley psychoacoustic testing facility in which the simulated sounds of modulated and evenly-spaced rotors were played to a group of listeners.
- Six rotor configuration sound simulations were tested. The 4-blade regular spacing was based on the Bell Model 427 helicopter. The 5-blade main rotor with regular spacing was designed to approximate the performance of the 427, but at reduced tip speed. Four modulated rotors – one with “optimum” spacing and three alternate configurations – were derived from the 5 bladed regular spacing rotor.
- The sounds were played to 2 subjects at a time, with care being taken in the speaker selection and placement to ensure that the sounds were identical for each subject. A total of 40 subjects participated. For each rotor configuration, the listeners were asked to evaluate the full overflight sounds in terms of noisiness on a scale of 1 to 10.
- The test results are now being compiled. Preliminary results indicate little to no “annoyance” benefit for the modulated blade spacing. For the level flight condition shown, the subjects preferred the sound of the 5-blade regular spaced rotor over any of the modulated ones. All the modulated rotors and the 4-blade regular spaced were judged more annoying than the 5-blade regular.
- A preliminary conclusion is that modulated blade spacing is not a promising design feature to reduce the annoyance for main rotors, although reduced tip speed does hold much promise for evenly spaced main rotors.

Future Plans: Look at more random spacing between blades to determine if the beating effect seen was caused by blade spacing similarities

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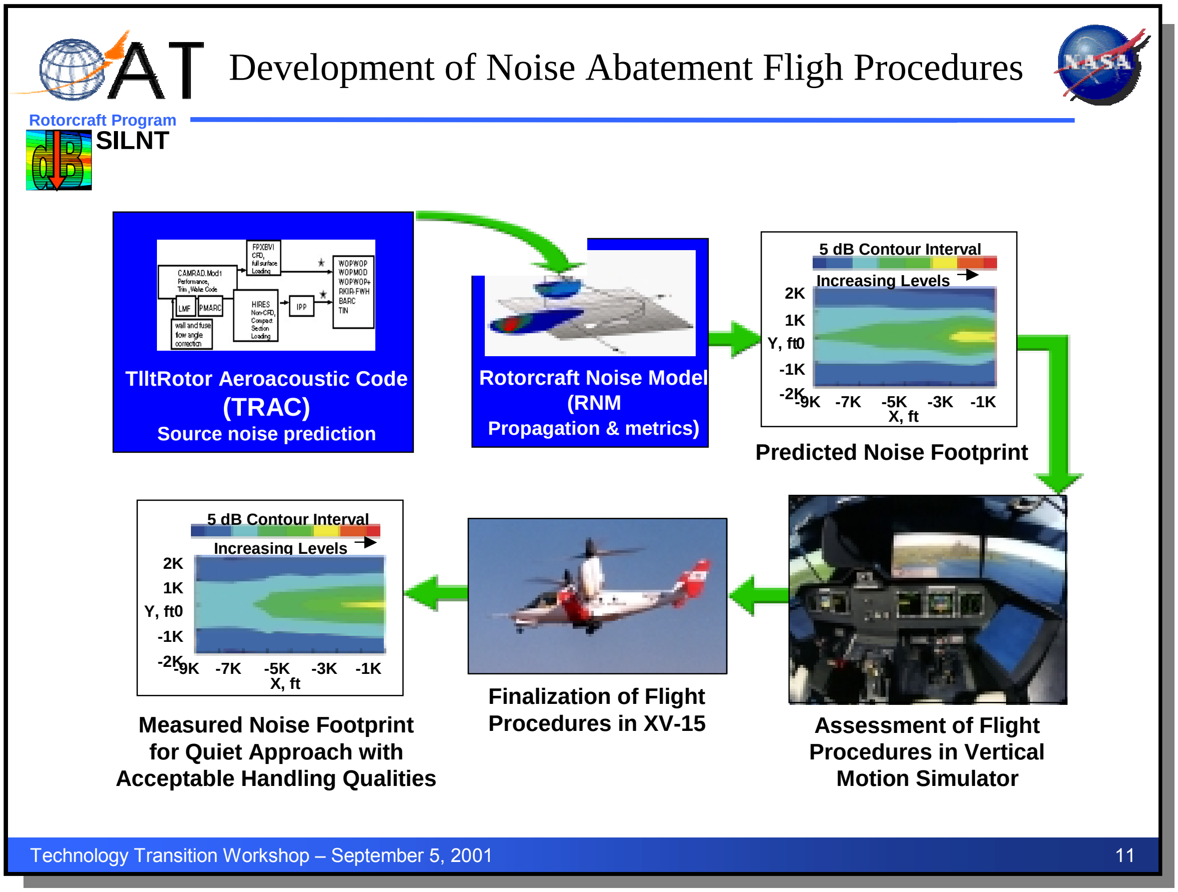


AT
Rotorcraft Program
Development of Noise Abatement Fligh Procedures
NASA
dB SILNT
TiltRotor Aeroacoustic Code
(TRAC)
Source noise prediction
Rotorcraft Noise Model
(RNM
Propagation & metrics)
5 dB Contour Interval
Increasing Levels
2K
1K
Y, ft0
-1K
-2K
-9K -7K -5K -3K -1K
X, ft
Predicted Noise Footprint
Assessment of Flight Procedures in Vertical Motion Simulator
Finalization of Flight Procedures in XV-15
5 dB Contour Interval
Increasing Levels
2K
1K
Y, ft0
-1K
-2K
-9K -7K -5K -3K -1K
X, ft
Measured Noise Footprint for Quiet Approach with Acceptable Handling Qualities
Technology Transition Workshop – September 5, 2001
11

TiltRotor Aeroacoustic Code (TRAC) Development and Validation

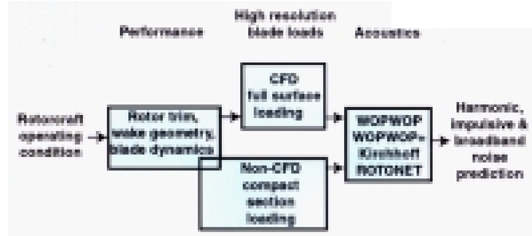
Rotorcraft Program

SILNT

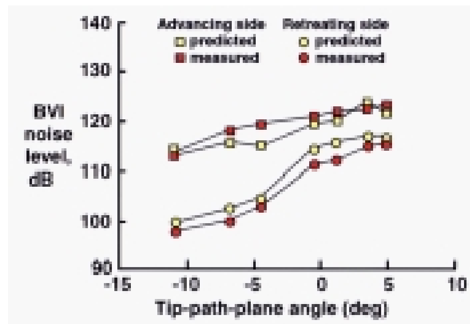
NASA/Army Bell Tiltrotor Aeroacoustic Test

15% scale model rotor in 14- by 22- foot W.T.

TiltRotor Aeroacoustic Code (TRAC)



Measured and Predicted BVI Noise Maximums



TiltRotor Aeroacoustic Code (TRAC) Development and Validation
Casey Burley, Doug Boyd, Tom Brooks

Goal: Develop full vehicle noise modeling capabilty and validate with measurement with wind tunnel and flight testing.

Shown: The NASA/Army Bell Tiltrotor Aeroacoustic Test 15% scale model rotor in 14- by 22- foot W.T. General flow and contents of the TRAC system. Example validation results.

Accomplishements: TRAC proprotor and rotor validation performed using Bo105, JVX, TRAM and XV-15 test data. The combined predictions of harmonic/BVI noise and broadband BWI and Self noise represent the first 'complete' main rotor-noise spectra prediction.

Plans: TRAC was a project of the SHCT Program and will be transitioned to the Rotorcraft Aeroacoustic System Prediction (RASP) code for continued flight noise prediction and system Analysis. This effort will include the improvement or inclusion of:

- improved source noise modeling
- rotor wake defininitio
- rotor/Body Interactions
- Maneuvers

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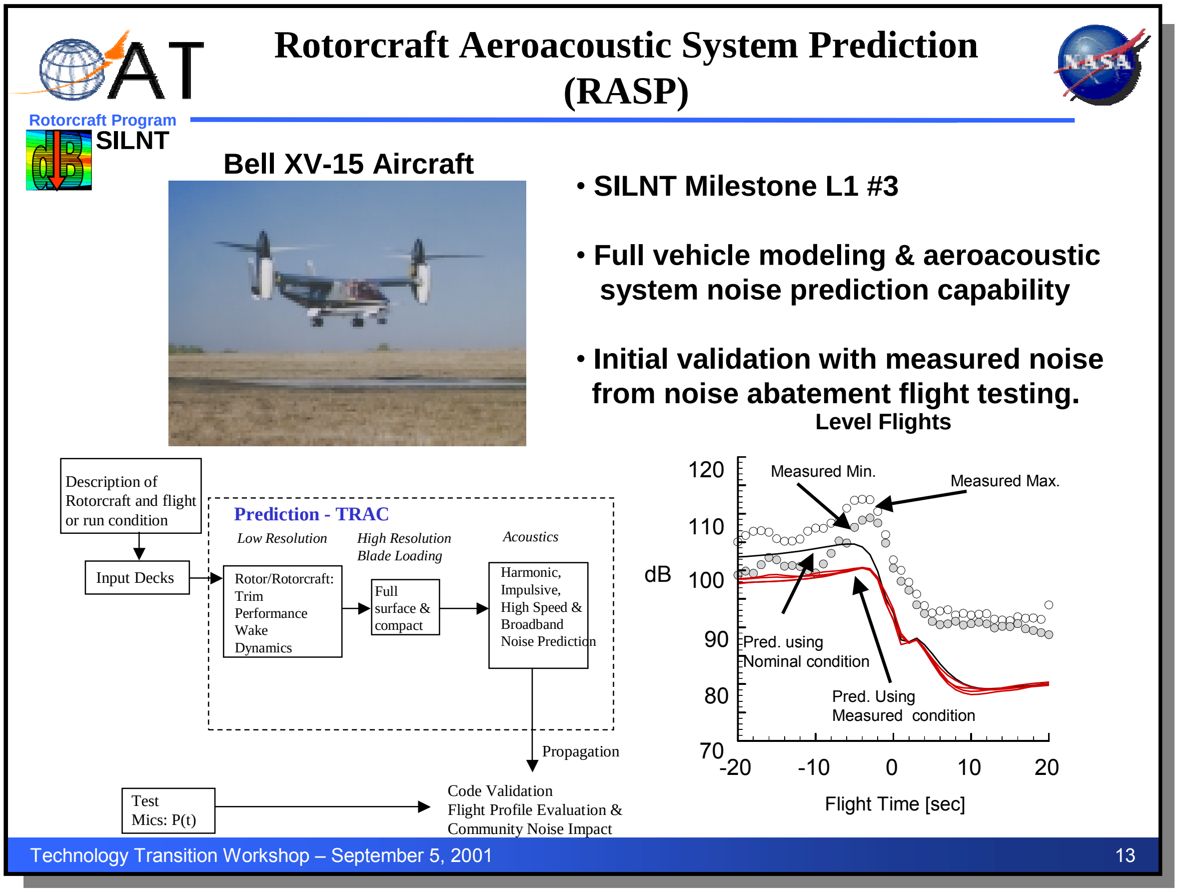

Rotorcraft Aeroacoustic System Prediction (RASP) Development
C. L. Burley, T. F. Brooks, D. D. Boyd Jr., D. A. Conner

Relevant Milestones SILNT L1 :
#4 Validated capabilities for noise prediction, modeling, and reduction for rotorcraft.
#3 Develop full vehicle noise modeling capability & validate with measurement from noise abatement flight testing.

Shown: Initial flight predictions using RASP and comparison with measured flight data from an XV-15 rotorcraft during steady level flight and descent conditions .

Accomplishment/Relationship to Milestone:

- The goal of the SILNT program is to provide analytical methods, advanced technologies and operational procedures that will improve ride quality, community and passenger acceptance by reduction of rotorcraft system noise and vibration.
- The Rotorcraft Aeroacoustic System Prediction (RASP) was utilized in predicting the noise on the ground during a steady level flight and descent conditions. Sensitivity of noise prediction to vehicle orientation, vehicle flight speed and descent rate were examined. Details of acoustic time histories were found to be sensitive, whereas integrated metrics were insensitive to the parameters considered.
- Comparison repeated measured flight acoustics found variability in flight condition and vehicle orientation as a function of flight time. Measurements were found to be within the expected range of repeatability for flight testing. However, variability found in measured flight condition and vehicle orientation parameters were found to have a significant effect on the measured acoustic time histories. A much less effect was found in the integrated noise metrics.

Plans: Perform comprehensive comparison of measured and predicted flight acoustics for XV-15 as well with available helicopter flight data. Enhance prediction capability for maneuver flight conditions in order to predict noise during flight abatement procedures.

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Advanced Rotor Aeroacoustic Modeling (ARAM)

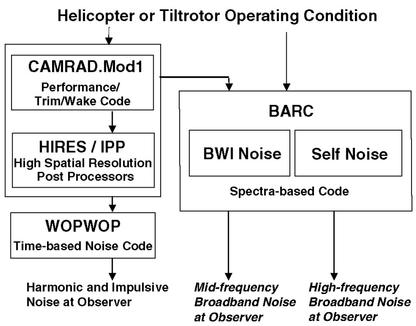
Rotorcraft Program

SILNT

- SILNT Milestone L1 #4
- Prediction of complete main rotor noise spectra (broadband + BVI noise)
- Validated with measured data for range of conditions (climb to steep descent)

Measured and Predicted Noise Spectra
(descent condition, advancing side microphone)

Prediction Code Elements



Advanced Rotorcraft Aeroacoustic Modeling (ARAM) Development Project
C. L. Burley, T. F. Brooks, D. D. Boyd Jr.

Relevant Milestones SILNT L1 :
#4 Develop and validate advanced, computational methods for broadband noise prediction.
#1 Validate prediction of main rotor noise by comparison with measured helicopter noise footprints.

Shown: Schematic of BARC and prediction of the complete noise spectrum and comparison with measurement from a Bo105 40% scale main rotor.

Accomplishment/Relationship to Milestone:

- The goal of the SILNT program is to provide analytical methods, advanced technologies and operational procedures that will improve ride quality, community and passenger acceptance by reduction of rotorcraft system noise and vibration.
- The Broadband Rotor Aeroacoustic Code (BARC) was developed and validated with acoustic data obtained from a Bo105 model scale main rotor for conditions ranging from steep descent to climb. BARC predicts and combines the broadband noise sources of Blade Wake Interactions (BWI) noise and blade Self noise.
- The first predictions of complete noise spectra were made and compared to measured data from a scale model main rotor. The broadband noise predictions, along with those of harmonic and impulsive Blade-Vortex Interaction (BVI) noise predictions demonstrated a significant advance in predictive capability for main rotor noise.
- In a complimentary program conducted under the NASA Aviation System Capacity Program, the tiltrotor rotor aeroacoustic code (TRAC) was developed and validated. Prediction validation was performed for model and flight rotorcraft (tiltrotor and helicopter). Initial comparisons with flight data were performed and compared well.

Plans: Completion BARC development for flight comparison. Perform comprehensive comparison of predicted and measured flight footprints for entire flight regime from climb to descent.

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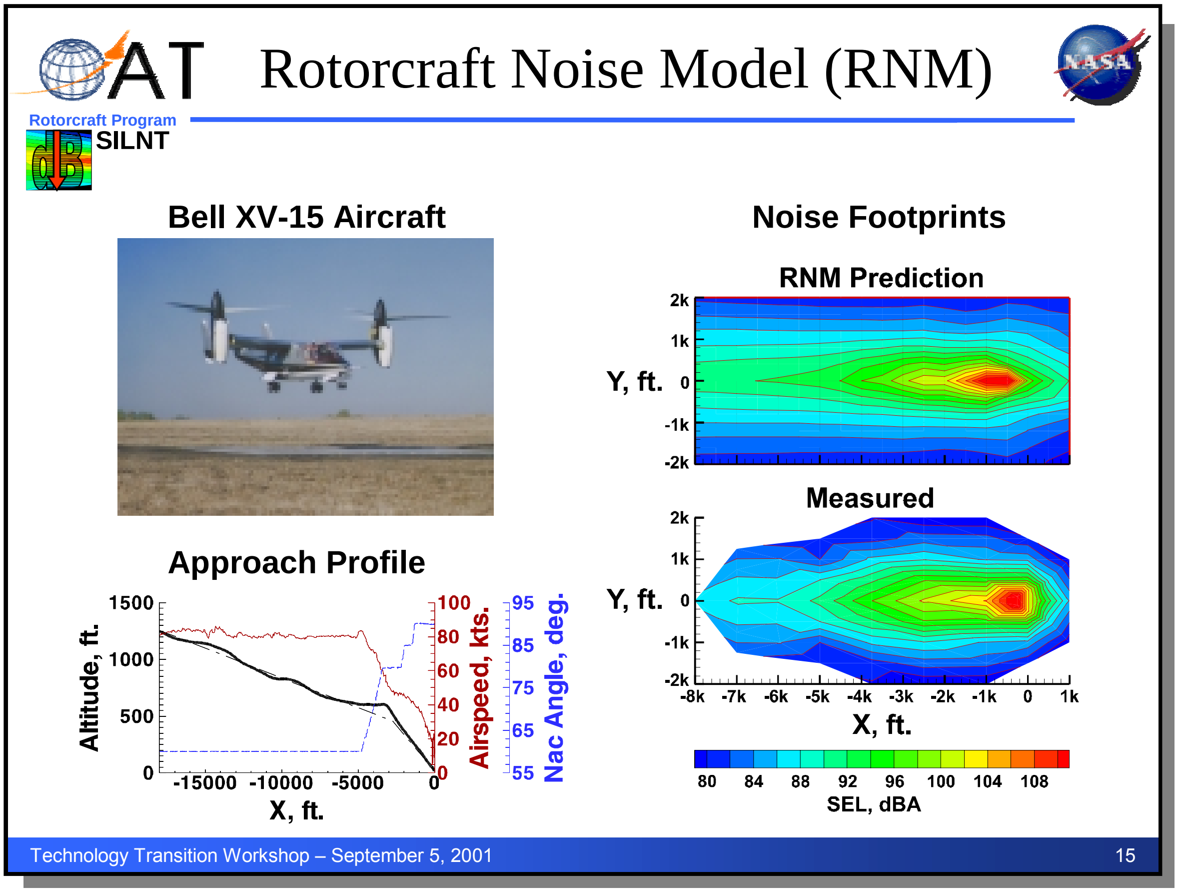

RNM Prediction Comparison with XV-15 Measured Footprint
David A. Conner

Relevant Milestone: SILNT3 – Develop full vehicle noise modeling capability and validate using measured noise footprints obtained from noise abatement flight testing; and SILNT4 – Validate capabilities for noise prediction, modeling, and reduction for rotorcraft.

Shown: Photo of test vehicle, graphic of approach profile, measured noise footprint, and RNM predicted noise footprint.

Accomplishment/Relationship to Milestone and ETG:

- Measured XV-15 noise footprints have been compared to noise footprints predicted by the Rotorcraft Noise Model (RNM) for the purpose of validation of RNM.
- The example comparison shown was for a complex, multi-segmented, decelerating approach, including nacelle angle changes.
- The example comparison shows good agreement between the measured and predicted footprints. Similar results were found for several other XV-15, V-22 and SP-412 comparisons.

Plans: RNM will be further validated for additional flight conditions and other vehicles using both multiple data bases and aeroacoustic predictions. Enhancements to RNM are planned to (1) improve low incidence angle predictions, (2) model non-steady state flight conditions (accelerations, turns, etc.) and (3) account for propagation effects in an inner-city setting where reflections off of buildings can significantly alter the noise footprints, thus providing a more robust prediction capability.

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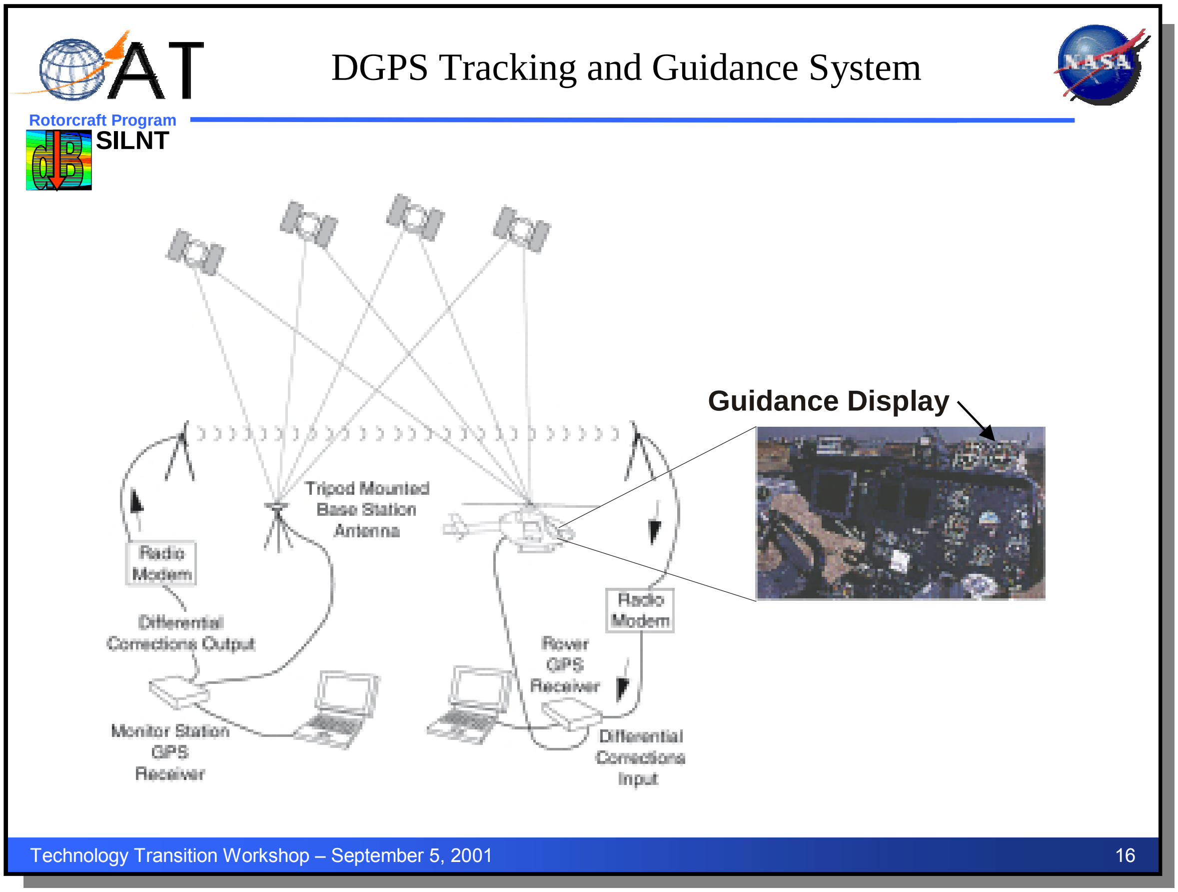

DGPS Tracking and Guidance System
David A. Conner

Relevant Milestone:

- SILNT3 – Develop full vehicle noise modeling capability and validate using measured noise footprints obtained from noise abatement flight testing.
- SILNT4 – Validate capabilities for noise prediction, modeling, and reduction for rotorcraft.

Shown: Sketch of DGPS system concept with photograph of a guidance display attached to top of instrument panel

Accomplishment/Relationship to Milestone and ETG:

- The DGPS tracking system will provide accurate time space position information relative to the ground-based microphone array. In addition, the pilot guidance system will improve flyover precision, thereby reducing test costs.
- Boeing-Mesa was awarded a contract to design and build the system and deliver it to NASA Langley. All system designs have been completed, all instrumentation has been procured, and all software has been written. System integration is nearly complete.

Plans: Customer acceptance demonstration flight test is planned to be conducted at UTSI, Tullahoma, Tennessee during 3rd week of September 2001. Upon acceptance, system will be delivered to NASA Langley. System will provide a valuable tool that will be utilized in future acoustic flight tests.

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Rotorcraft Program

SILNT

HART II Test

Technology Transition Workshop – September 5, 2001 17

HART II Test

Casey L. Burley, Tom F. Brooks

Goal: Develop and validate rotor wake and acoustic codes to advance systems noise prediction capabilities

Task Benefit/Payoffs:

- Provide comprehensive database for source noise model development
- Improved prediction codes for quiet rotor design and low noise operation development

Task Deliverables:

- Comprehensive benchmark database
- Advanced prediction codes: LMF for rotor wake, and BARC for broadband and BVI noise

Approach:

- Conduct HART II in DNW
- Obtain 3-C PIV rotor wake measurements, acoustics (broadband and BVI), unsteady airloads and blade motion
- Theoretical and code development for wake, unsteady airloads and acoustic modeling

Partners:

- NASA, DLR, AFDD, ONERA, DNW
- Virginia Polytechnic Institute., Jolly Development Corporation, Florida State University

Customers: U.S. Rotorcraft industry, government, U.S. Military

Plans: Conduct the HART II test in late September. Analyze and publish test results in FY02. Validate prediction codes using test data.

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Langley Task Status Summary

Rotorcraft Program

SILNT

RAPID

Tasks	Funding Source	Status	Continuation actions
RAPID			
Active Twist Rotor (Joint with SILNT)	NASA RC/Army	V1 Test Complete	
Projection Moire Interferiometry	NASA RC	Fielded	
Wing RotorAeroelastic Testing System	NASA RC/Army	Repaired	
Stringer Pull-off Prediction	NASA RC/Army	On-going	
SILNT			
Low Noise Planform	NASA RC	Complete	
Modulated Blade Spacing	NASA RC	Complete	
Development of Noise Abatement Procedures	NASA RC/SHCT/Army	On-going	
TiltRotor Aeroacoustic Code	NASA RC/SHCT/Army	Complete	
Rotorcraft Aeroacoustic System Prediction	NASA RC	On-going	
Advanced Rotor Aeroacoustic Modeling	NASA RC	On-going	
Rotorcraft Noise Model	NASA RC/SHCT/Army	V1 Fielded	
DGPS Tracking and Guidance System	NASA RC/SHCT/Army	Near Delivery	
HART II Test	NASA RC/SHCT	Nearly Complete	

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Goal

- reduce the rate of aviation fatalities - by 80% in 10 years
  - by 90% in 25 years
- avoid increase in fatalities predicted with the doubling of operations

Aviation Safety

NASA teamed with the FAA, DoD and the aviation industry

- to advance aviation safety
- identified safety as NASA's top priority
- approved the formation of the Aviation Safety Program
- encouraged redirection of basic research to safety-related topics

Helicopter Safety

SAFOR >> improving the safety of civil *helicopter* operations.

analysed helicopter accidents and incidents

hosted workshop to identify problems and promising research topics

Team: NASA-Ames, other government agencies, industry and universities

Projects to Prevent Accidents

Safety through Flight Controls

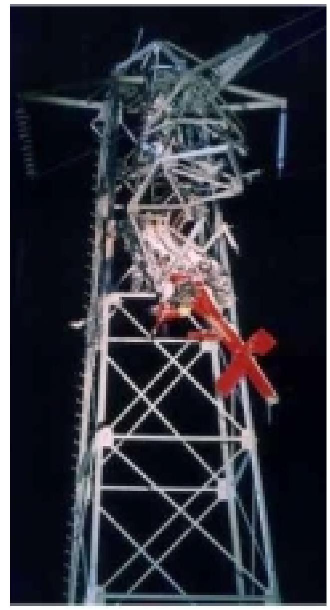
- Control Designer’s Unified Interface
- RIPTIDE
- RASCAL
- Design Guidance for IFR Certification
- Carefree Maneuvering
- Rotorcraft Unmanned Aerial Vehicles

Safety through Pilot Aiding

- Untethered Helmet Mounted Displays
- Hazard Alerting Displays
- Cockpit Display of Traffic Information

Safety through Pilot Training

- Course Of Action Training Tool
- Safety Website
- Autorotation training

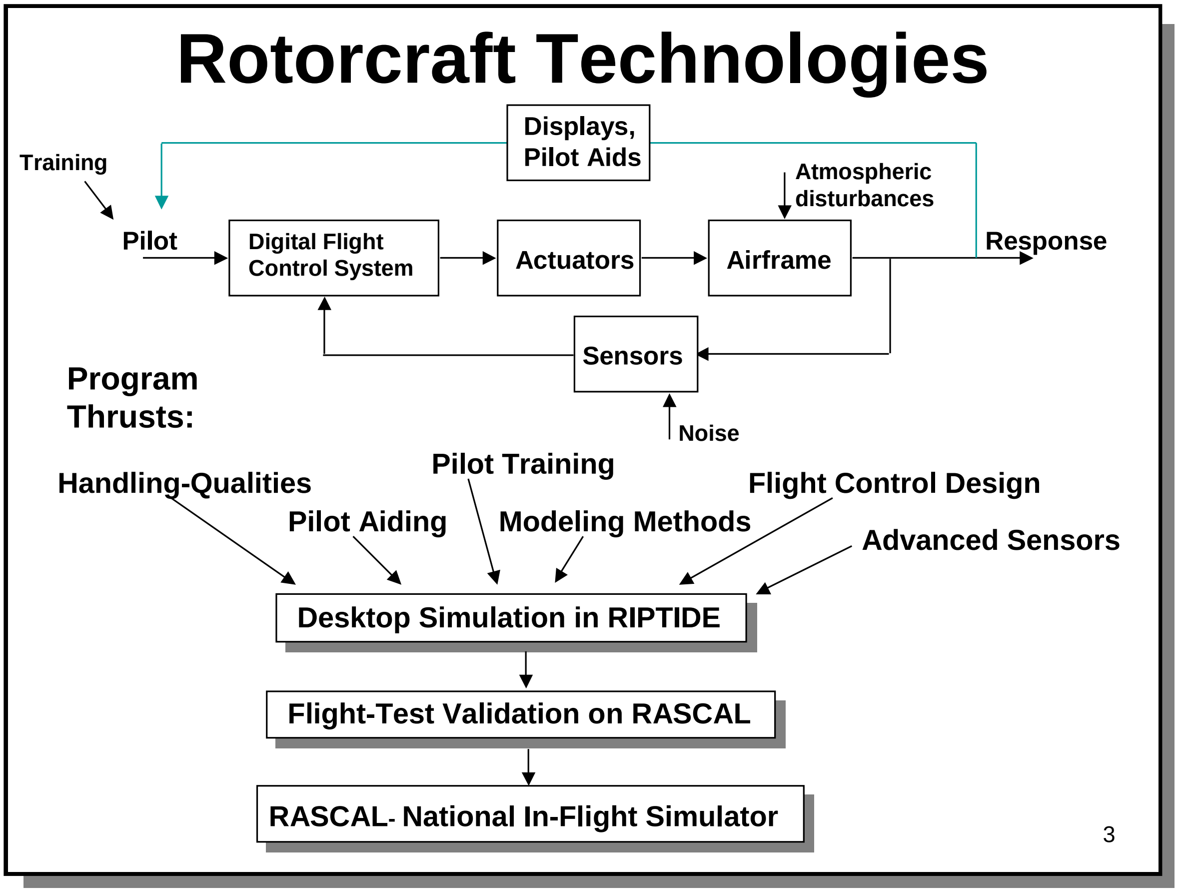


2

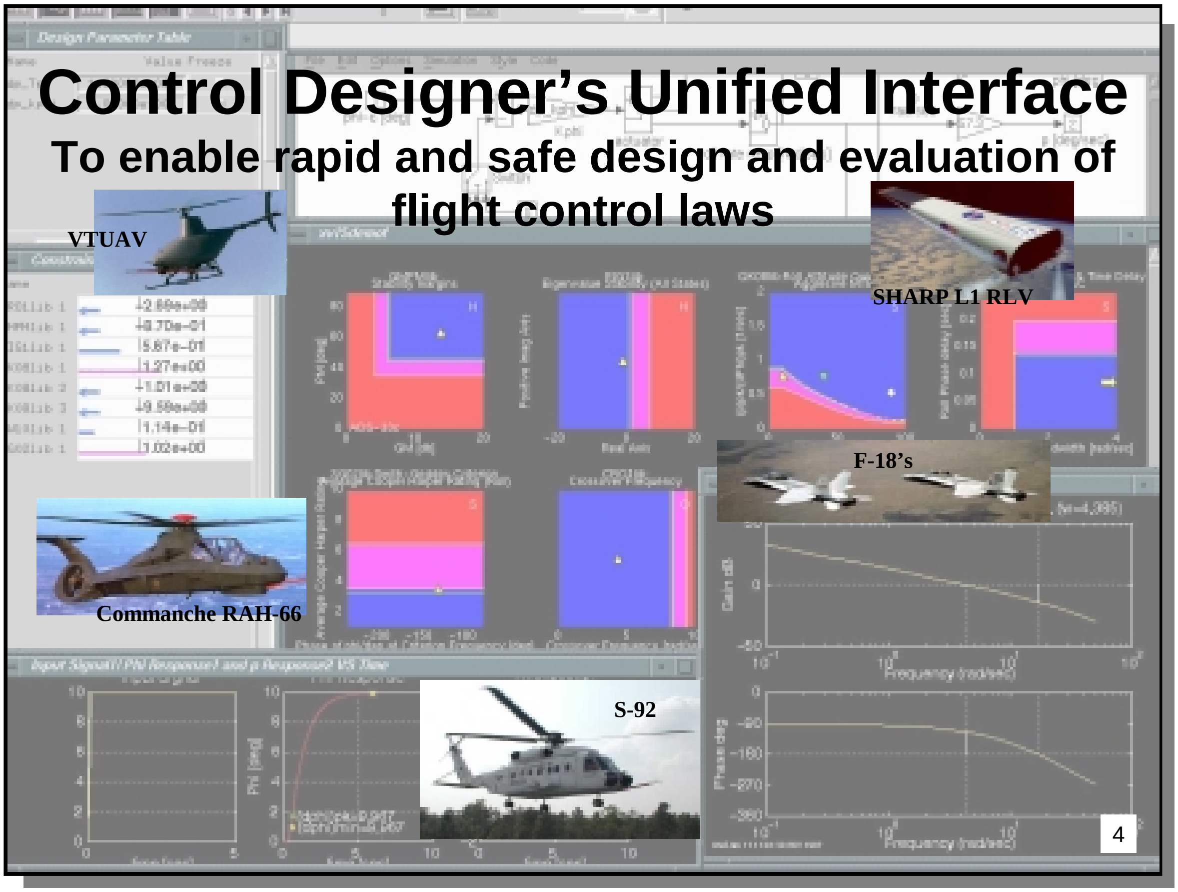
Approach

Perform accident analyses to determine why helicopters have accidents.

Safety through	**To address**	**By doing**
Flight controls	safe manuevering	control law design
		virtual flight testing
		RUAV control law development
		IFR operations
Pilot aiding	loss of situational awareness	cockpit display development
	obstacle avoidance	pilot aid design
Pilot training	pilot error	safety awareness improvement
	inexperience	training tools development



Handling-Qualities	Specifications, Flight test techniques Generic studies, Limited authority, Envelope limiting
Modeling Methods	Simulation validation/improvement Higher-order linear (FCS) models, System identification
Flight Control Design	Model following, Optimization Integrated design tools, Advanced rotor controls
Advanced Sensors	Display formats/dynamics, Blade motion sensors
Pilot Aiding	Cockpit displays, Tactile cueing
Pilot Training	Safety awareness, Physical & mental skill trainers
Desktop Simulation on RIPTIDE	Design and evaluation studies
Flight-Test Validation on RASCAL	System design validation studies Flight control and display laws / Perf. Validation
RASCAL- National In-Flight Simulator	Industry/government basic research, new systems evaluations



Goal
To enable rapid and safe design and evaluation of flight control laws.

Accomplishments to Date

- High level specifications can be easily implemented on CONDUIT to define fundamental actuator motions and controls.
- CONDUIT has been used to design flight control systems for the following manned vehicles: RAH-66 , HACT Demonstrator, Boeing JSF (X-32A), RASCAL, F14D - Block Upgrade, SH-2G (Kaman), Sikorsky S-92, F-18 (Dryden)
- CONDUIT has been used to design flight control systems for the following unmanned vehicles: Marine “BURRO” (KAMAN), Carnegie Melon University R-50 UAV, Microcraft 9” iStar, Navy VTUAV (Northrop-Grumman, Ryan Aeronautical), Sharp L1 RLV Demonstrator
- RASCAL just successfully completed a peer review (including participants from Dryden) of its safe in-flight concepts - might engage before workshop…

Future Plans / Opportunities

- Flight validation of CONDUIT-designed advanced control laws in RASCAL.
- Further development and design of control laws for other platforms

POC
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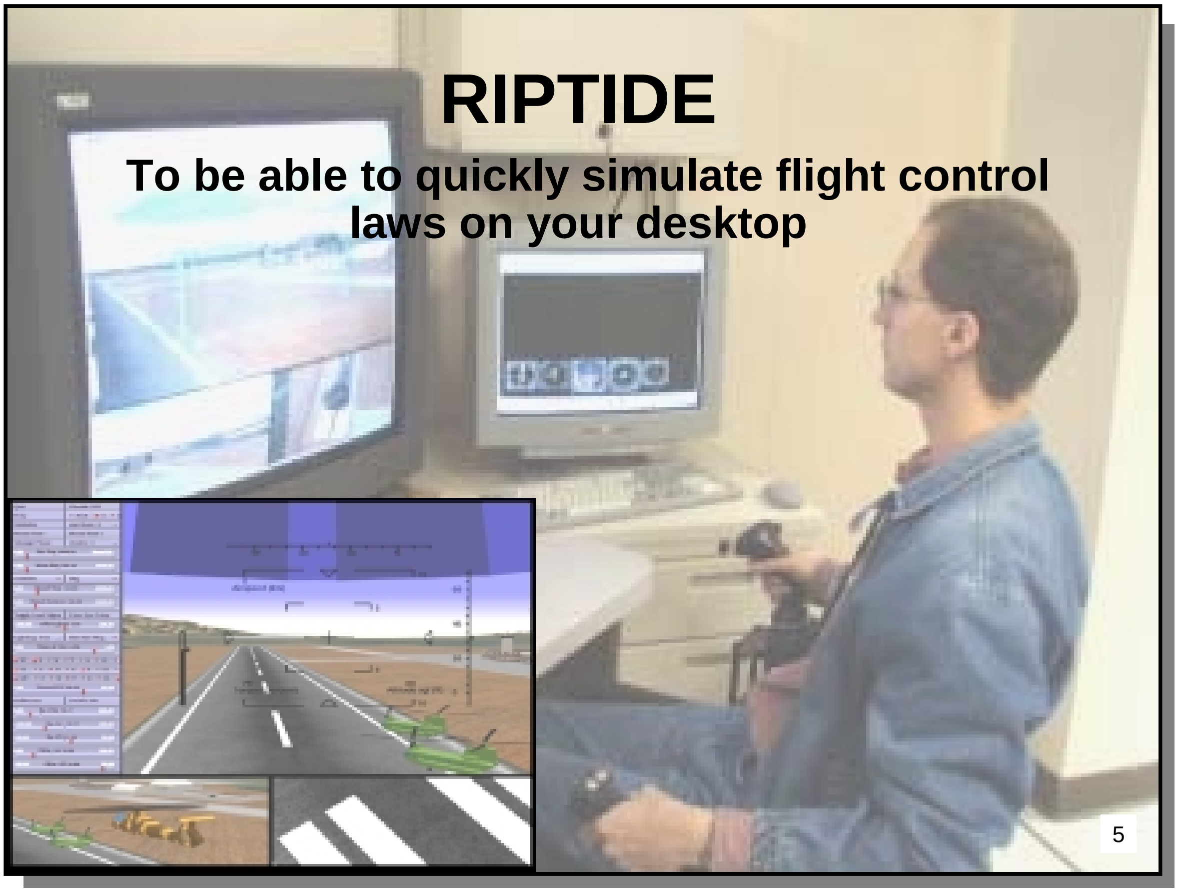

Goal

The goal of the Real-time Interactive Prototype Technology Integration/Development Environment (RIPTIDE) is to be able to quickly evaluate flight control laws on your desktop.

Accomplishments to Date

- Integrated existing tools for simulation, control system design/optimization, display law development
- Provided communication between them via shared memory so tools can function in conjunction with each other.
- Develop real time executive to control orderly operation of processes.
- Combined into high-fidelity, real time, engineer/pilot-in-the-loop rapid prototyping and evaluation environment. Specify configuration, flight condition, maneuver / mission, and environment.
- Transferred to Industry via Boeing and Wright Labs

Future Plans / Opportunities

- Improve simulation fidelity by improving visual system, tie in Head Mounted Display
- Develop and evaluate autonomous guidance and control algorithms
- Use PDA for waypoint navigation
- Perform piloted simulation of S-92 helicopter with CONDUIT designed control laws

POC

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Goal
The goal of the RASCAL (Rotorcraft Aircrew Systems Concepts Airborne Laboratory) helicopter is to provide a flying platform for safe evaluation of flight control and cockpit integration concepts.

Accomplishments to Date

- Laboratory has been created for investigation of new aeronautical systems, flight control and crew systems technologies
- Advanced instrumentation: carrier phase DGPS precision navigation, Health and Usage Monitoring System, and instrumentation for measuring both vehicle states and rotor states
- Research flight control system is C-language programmable, has full authority servos, and incorporates a fail-safe design concept
- Full in flight engagement of RASCAL's research flight control system took place August 31st

Future Plans / Opportunities

- Validation of high bandwidth control law display design
- Capture data for turbulence model development for civil helicopter flight control certification
- Test displays for terrain and traffic avoidance
- Support technology development for manned and unmanned air vehicles
- Innovative Flight Control Concepts - carefree maneuvering with active sidestick
- Rotor State Measurement & Feedback - use real time feedback for flight control

POC
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Goal

The goal of developing design guidance for civil helicopter IFR certification is to minimize civil helicopter accidents involving inadvertent flight into bad weather.

Accomplishments to Date

- Completed initial simulation to investigate civil helicopter IFR workload and to develop the basis for eventual certification methods and design guidance for civil helicopters.
- Civil Helicopter IFR Simulation Tool successfully developed for VMS.
- Initial results show that workload can be very high, especially in turbulence.
- Only the autopilot was consistently rated as low workload. More data is required to determine what is desirable, and what is safe enough.

Future Plans / Opportunities

- Obtain sufficient data to make initial estimates of rotorcraft dynamics/SAS/Autopilot for safe IFR operations
- Assess the effect of SAS failures

POC

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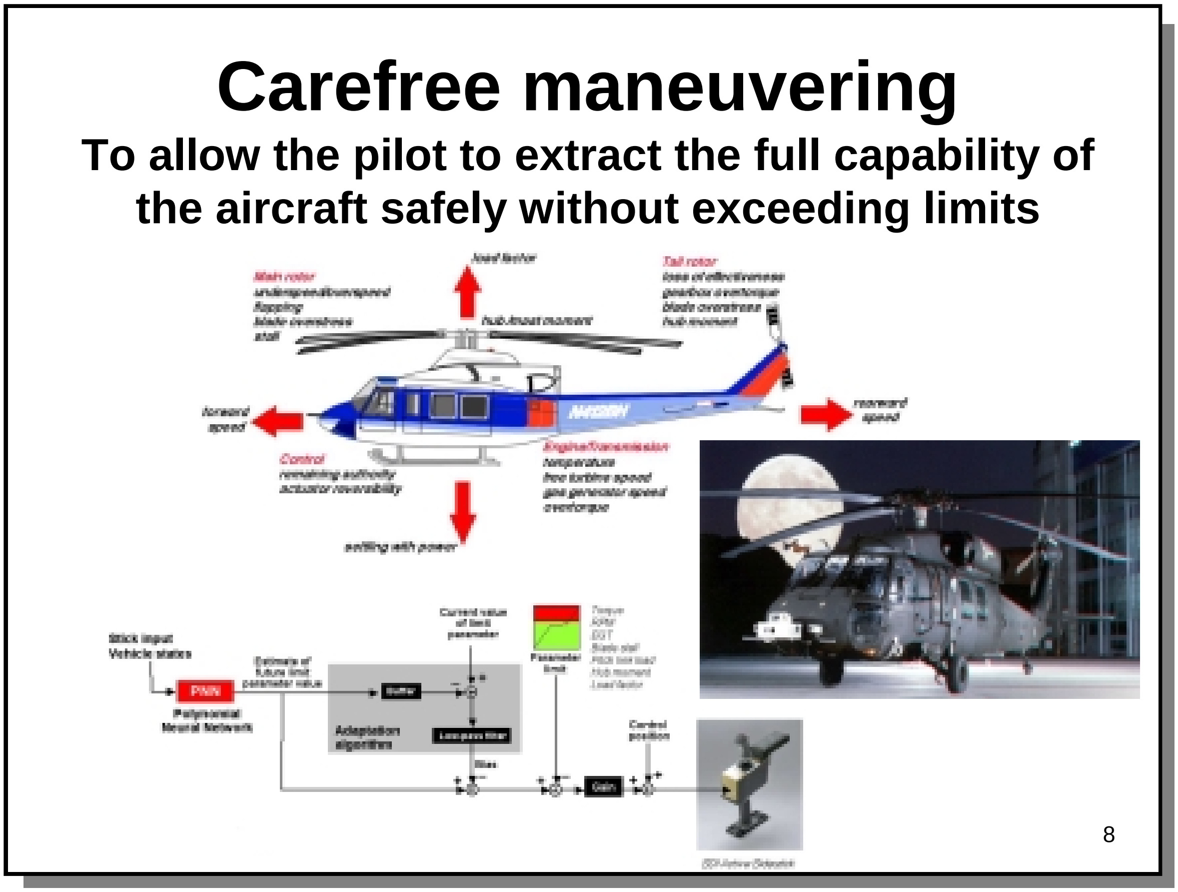

Goal
The goal of carefree maneuvering is to allot the pilot to extract the full capability of the aircraft safely without exceeding limits.

Accomplishments to Date
- Several simulations conducted - two-axis sticks tested in VMS
- Reduction of envelope exceedence was successful
- Three-axis stick developed for RASCAL - NASA SBIR-funded, $600k, 3 yr.
- RASCAL Installation and Testing -HUMS installation, Flight testing of digital sensors
- Design and test of Bell 412 tactile cueing system
- NRC/CDF flight test, NASA Ames Director co-funded, $180k, 18 mo.

Future Plans / Opportunities
- Integration of three-axis stick into RASCAL
- RASCAL Installation and Testing - Data gathering using HUMS installation
- Flight testing of digital sensors, Test of SDI exceedance in future plans
- Continued support of Bell 412 effort at NRC
- HACT - Initiation of Phase 2 flight demonstration effort

POC
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Goal
To reduce the time and cost of a Rotorcraft Unmanned Autonomous Vehicle (RUAV) flight control system development effort and achieve satisfactory handling-qualities.

Accomplishments to Date
- Developed a seamless interface between design an optimization tool, a desktop simulation tool and external simulation models.
- Demonstrate control law optimization and simulation of 9” diameter ducted-fan UAV
- Flight test validation of new RUAV tools
- Cooperative Research Development Agreement to support DARPA OAV (FCS) with Honeywell/AeroVironment

Future Plans / Opportunities
- Other RUAV research applications in 2000/2001: VTUAV (Navy/Northrop), Burro (Kaman), R-50 (CMU)
- Address key technical challenges: RUAV specific sensors and controls, dynamic response
- Design requirements for UAV mission, integration of RUAV design tools

POC
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Goal
The goal of developing an untethered head mounted display is to improve pilot –vehicle performance through better situational awareness.

Accomplishments to Date

- A light weight, low power, untethered HMD has been selected as an appropriate candidate for this project.
- This HMD has been integrated into the RIPTIDE research simulator environment.

Future Plans / Opportunities

- Determine performance limits with respect to reconstruction of a motion signal
- Develop embedded algorithms for signal up-sampling and decoding

POC
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Goal
The goal of the hazard alerting displays work is to help pilots avoid hitting things. This display helps cropduster pilots avoid wires.

Accomplishments to Date

- Interviews were conducted with agricultural applicators to understand the complex nature of this pervasive problem.
- Based on these interview, an appropriate wire alert was developed.
- A simulation has been conducted to test the effectiveness of wire alerting.
- Analysis of the data has shown that wire alerts can reduce strikes and improve consistency of performance.

Future Plans / Opportunities

- Simulation of avoiding unseen wires for greater realism.
- Tactile cueing (steering cue & hazard alert) in seat back (with U.W.Florida)
- Demonstration to Trimble.

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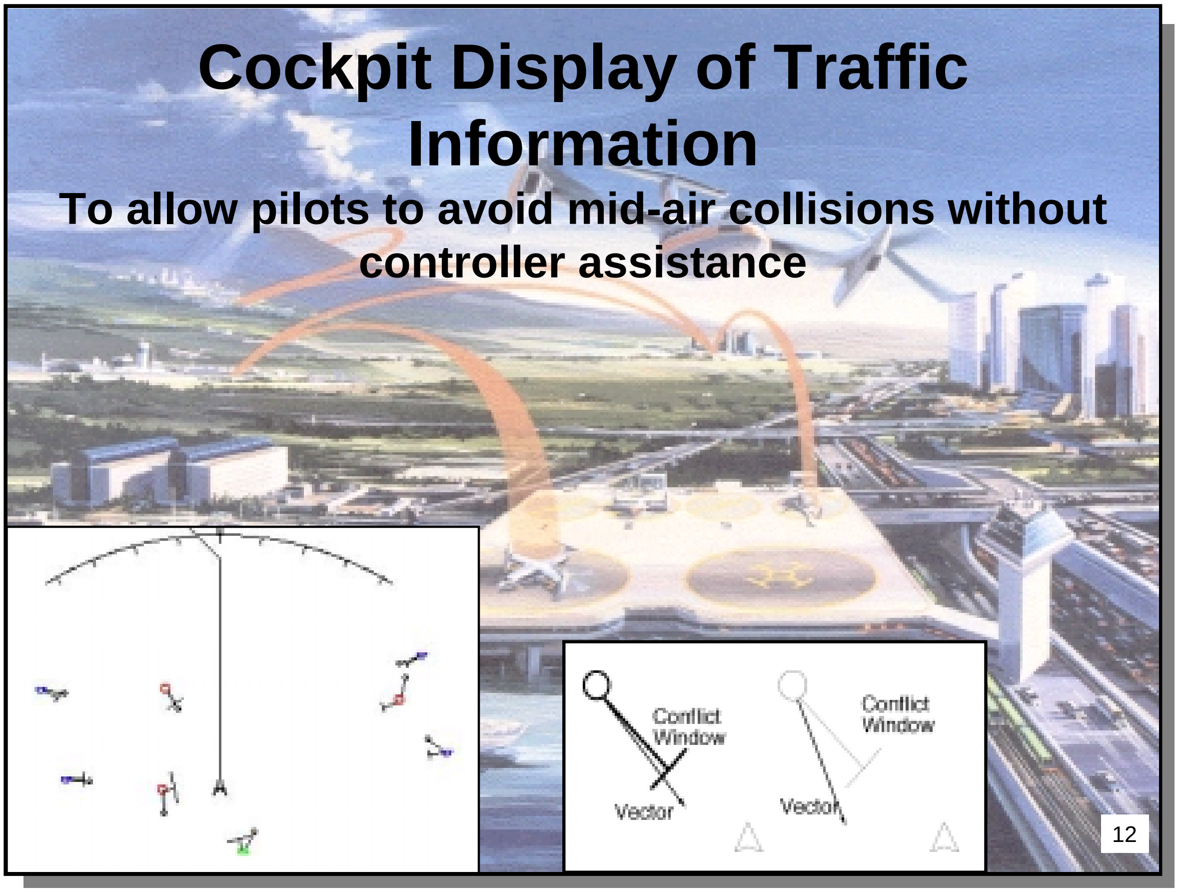

Goal

The goal of Cockpit Display of Traffic Information work is to allow pilots to avoid mid-air collisions without controller assistance.

Accomplishments to Date

- Developed the display concept for traffic avoidance with multiple variations.
- Conducted a simulation which tested four display configurations in non-real-time laboratory task.
- Analysis of data indicates that one configuration is particularly helpful in assisting identification of potential mid-air collisions.

Future Plans / Opportunities

- Simulate and evaluate the displays in identifying multiple conflicts.
- Simulate flight with conflict detection.

POC

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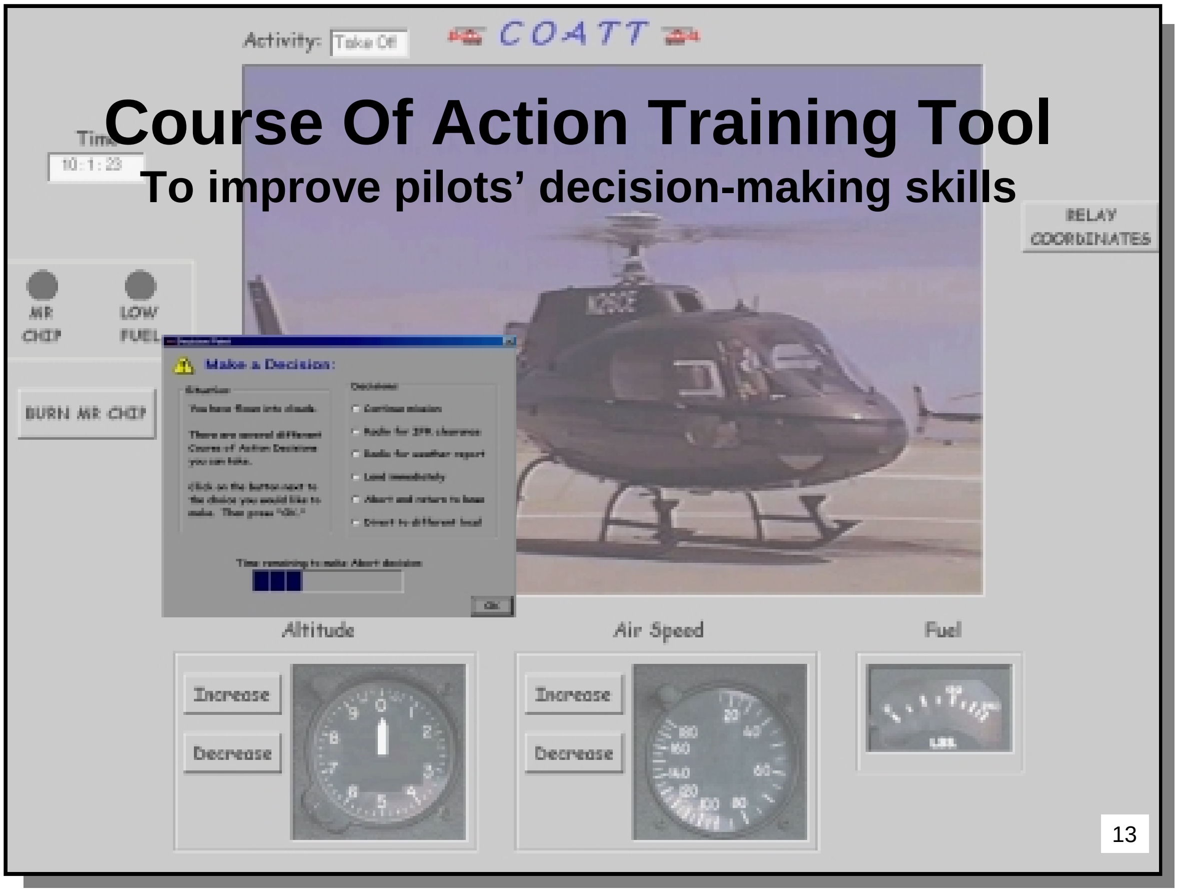

Goal

This Course of Action Training Tool is designed to improve pilots' decision-making skills and reduce the number of accidents due to pilot error and inexperience.

Accomplishments to Date

- Typical emergency medical transport (EMT) mission scenarios were defined
- A decision network was developed including nodes for the environment, aircraft states, and external events.
- A prototype, low-cost decision trainer was developed which integrates computer simulation, full motion video, still photographs, and audio.
- The prototype is undergoing field evaluation.

Future Plans / Opportunities

- Incorporate improvements based on feedback from field test.
- Transition to web based trainer.
- Expand training application to other missions.

POC

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Goal

The goal of the NASA helicopter safety web site is to reduce the accident rate by giving pilots a one-stop shop for helicopter safety information.

Accomplishments to Date

- The accident analyses are complete and have been published.
- The NASA Helicopter Safety Web Site “safecopter” has been posted
- Columns: updates from the FAA, reprints of Rotor & Wing articles, Aviation Safety Reporting System articles, “autorotation” articles, Bell’s Heliprops, accident summaries and statistics.
- Provides information on safety aids and a list of links to other safety minded helicopter websites.
- The website is receiving hits from ~2000 sites per month.

Future Plans / Opportunities

- Add an economic analysis of an accident, more mission specific information, training and maintenance sections.
- Add searchable databases for accidents and safety articles.
- Develop interactive illustrations of potentially risky maneuvers, vehicle states, & failures.

POC

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Goal
The goal of the autorotation training task is to reduce the autorotation accident rate through simulation.

Accomplishments to Date

- A simulation was conducted to examine the fidelity requirements of motion and the contributions of texture and grid upon successful autorotation performance.
- The critical cues of attitude, horizontal speed, and vertical speed were measured objectively and subjectively.
- The simulation produced some distinct differences between the conditions which will feed into recommendations for an autorotation simulator.

Future Plans / Opportunities

- Develop a head up display for autorotation training.
- Conduct a VMS experiment using R-22 model, integrating best ideas to date.
- Perform transfer of training study.

POC
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SAFOR Status

TASKS			
Item	Funding Source	Status	Continuation actions
Safety through Flight Controls			
Control Designer's Unified Interface	**NASA/ Army**	**Nearly complete**	**Army - partial**
RIPTIDE	**NASA/ Army**	**Complete**	**Army - partial**
RASCAL	**NASA/ AvSP**	**Engagement imminent**	
Carefree Maneuvering	NASA	**Ongoing**	**Army - partial** **RASCAL flts not included**
Design Guidance for IFR Certification	NASA	**Ongoing**	
Rotorcraft Unmanned Aerial Vehicles	NASA/ Industry	**Ongoing**	**Industry, Army - partial** **NASA - Intelligent Systems**
Safety through Pilot Aiding			
Untethered Helmet Mounted Displays	DARPA/NASA	**Ongoing**	**DARPA**
Hazard Alerting Displays	NASA	**Ongoing**	**Army**
Cockpit Display of Traffic Information	NASA	**Ongoing**	
Safety through Pilot Training			
Course Of Action Training Tool	NASA	Phase 1 complete	
Safety Website	NASA	Phase 1 complete	
Autorotation training	NASA	**Ongoing**	

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Rotorcraft Program

NASA Glenn Tasks

Safe All-weather Flight Operations for Rotorcraft
(SAFOR)

Revolutionary Approaches to Produce Innovative Designs
(RAPID)

Select Integrated Low Noise Technologies
(SILNT)

James J. Zakrajsek
NASA Glenn Research Center

Rotorcraft Program

GRC Rotorcraft Drive System Research Overview

Overall Objective:

Develop advanced drive system technologies that make significant improvements in safety, noise, and design efficiency through improved physics-based modeling that is complimented with experimental validation.

Approach:

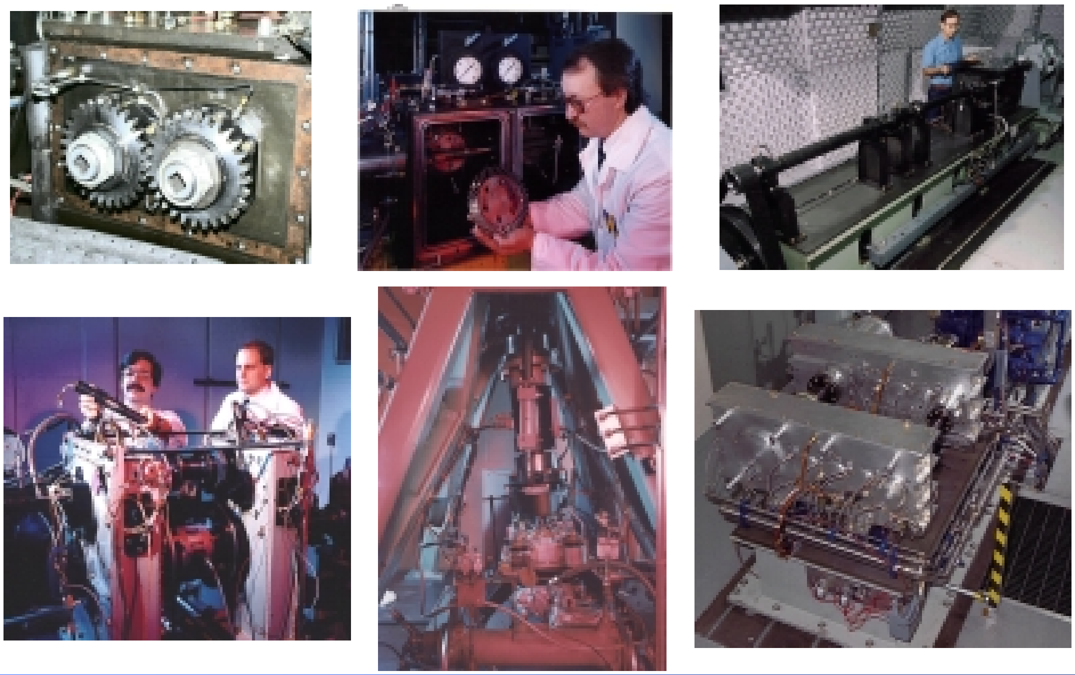
- In-house experimental and analytical activities
  - > 25 years of aerospace drive system research experience
  - > 10 years of intimate company-government interactions
  - Company liaisons – regular visits to the manufacturer
- Grant activities
- SBIR
- NRTC collaborative studies

The overall objective of the rotorcraft drive system research at Glenn is to develop advanced drive system technologies that make significant improvements in safety, noise reduction, and design efficiency.

AT

Rotorcraft Program

GRC Experimental Facilities for Drive System Research



Technology Transition Workshop – September 5, 2001 3

Glenn Research Center has a number of unique, world class experimental facilities for drive systems research. The research facilities include components test rigs to study various parametric effects on the fatigue characteristics of gears, along with transmission test rigs to study overall system effects.

Drive System Research Topics

Rotorcraft Program

Safe All-Weather Flight Operations for Rotorcraft

- Gear thermal management for fail-safe operation under minimum lubrication conditions
- Drive system sensor fusion for increased reliability of HUMS systems
- Gear crack propagation studies - Guidelines for ultra-safe design

Revolutionary Approaches to Produce Innovative Design Technologies

- Application of nano-tubes to drive system components to dramatically increase strength and reduce weight
- Variable speed drive system studies for future vertical lift aircraft
- Gear surface engineering research to increase power to weight metric
- Gear superfinishing research to improve power density and efficiency

SILNT- Select Integrated Low Noise Technologies

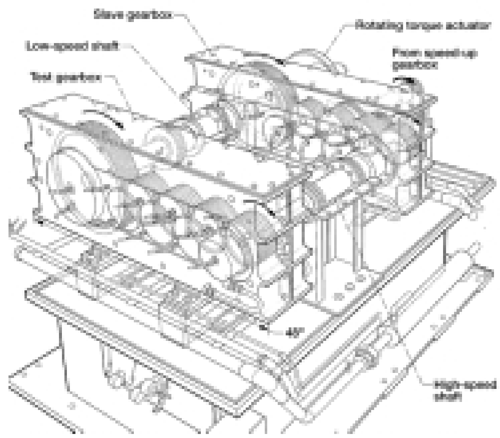
- Development of wave bearing to reduce gear noise and gear-induced vibration
- Technologies to reduce gear noise at the source

Gear Thermal Management for Fail-Safe Operation Under Minimum Lubrication Conditions

Rotorcraft Program

Safe All-Weather Flight Operations for Rotorcraft

Develop an understanding of the thermal behavior of high speed gear systems operating in normal and emergency conditions that include loss of lubrication



Technology Transition Workshop – September 5, 2001 5

Goal

Develop an understanding of the thermal behavior of high-speed helical gear train systems operating in normal and emergency conditions that include loss-of-lubrication on full scale, aerospace quality test hardware.

Accomplishments to Date

- Facility designed, fabricated, and installed at NASA Glenn Research Center
- Facility operated to full speed (15000 RPM) and power (5000 hp) condition for baseline test hardware (V-22) at various lubrication conditions

Future Plans / Opportunities

- Continue baseline tests for evaluating the effect of shrouds and heat sinks
- Evaluate the effectiveness of coatings and superfinishing on gear system thermal behavior
- Conduct loss-of-lubricant tests on baseline hardware
- Continue testing on three different gear design configurations

POC

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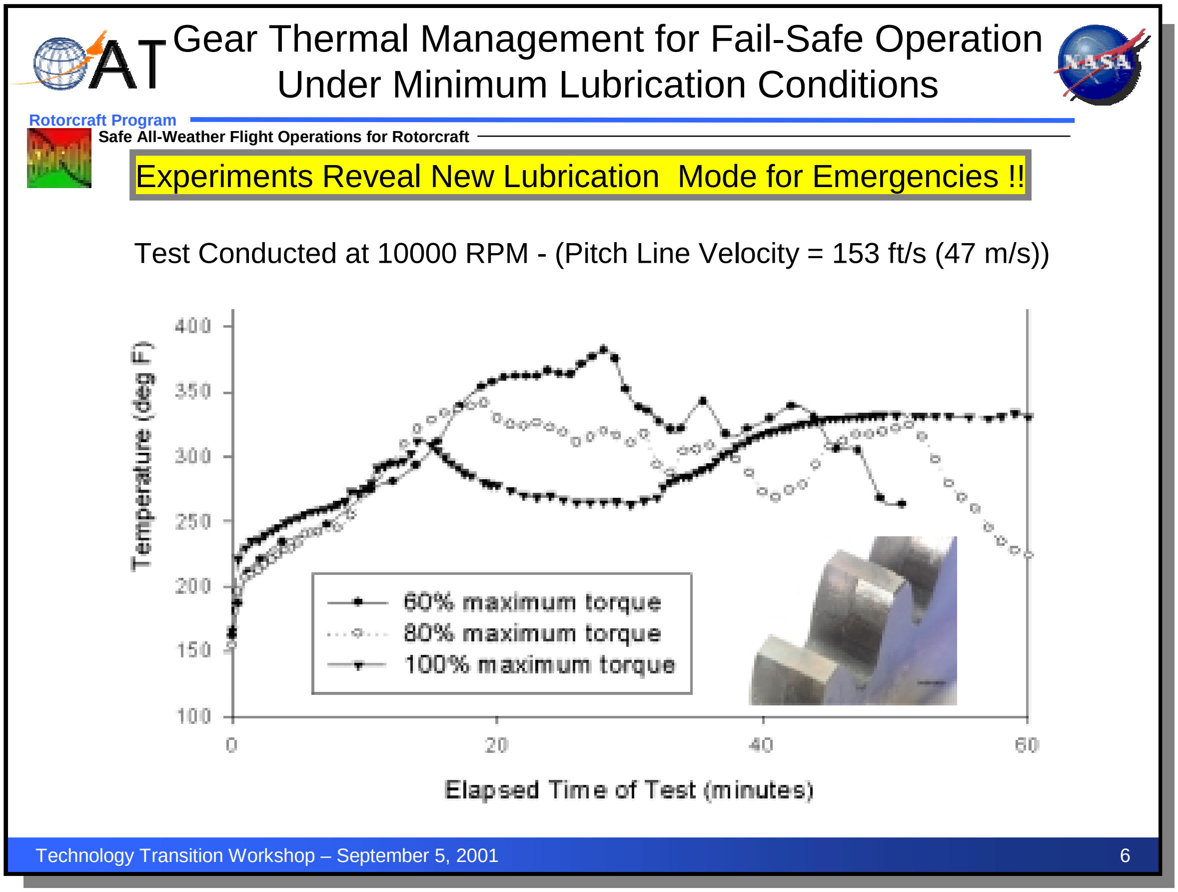

Goal

Develop an improved emergency lubrication methodology that will significantly reduce the weight, size, and complexity of current systems required to satisfactorily survive loss-of-lubrication operation.

Accomplishments to Date

- Component testing on current synthetic turbine engine lubricants evaluated and documented.
- Testing of advanced lubricant that has low friction properties at elevated temperatures is underway

Future Plans / Opportunities

- Continue baseline tests for evaluating the effect of lubricant constituents and flow rate requirements that will be verified through extended testing at the component level.
- Evaluated effectiveness in full scale high speed helical gear train system

POC

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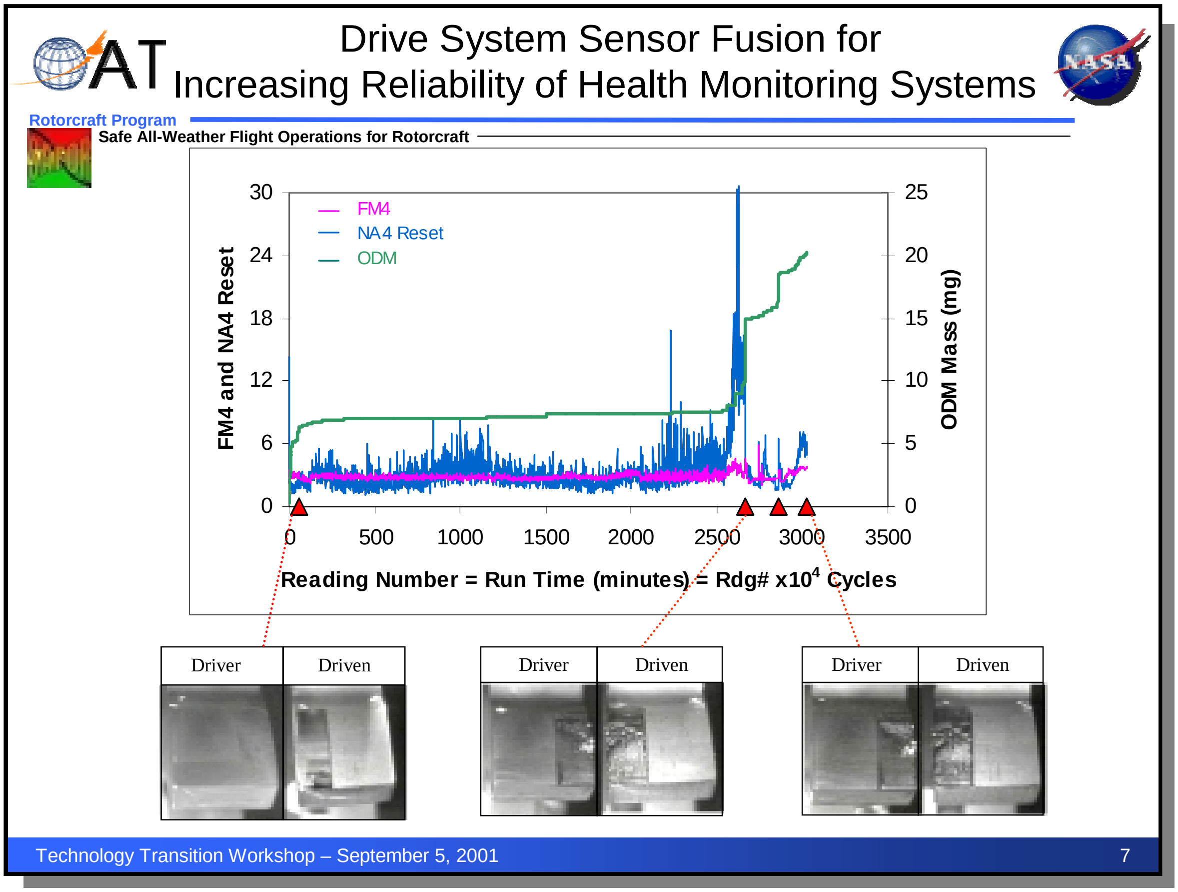

Goal

Perform tests in the NASA Glenn Spur Gear Fatigue Test Rig to assess the individual integrity of the oil debris sensor and vibration algorithms FM4 and NA4 to verify all are good predictors of transmission health

Accomplishments to Date

- Verified change in oil debris mass is comparable to vibration algorithms in detecting pitting damage. Results published in NASA TM 210371 presented at the 13th International Congress on Condition Monitoring and Diagnostic Engineering Management, December 2000.
- Found vibration algorithm NA4 sensitive to minor load changes. Developed a technique to minimize the effect of load on NA4. This technique was published in NASA TM 210671 presented at the 55th Meeting of the Society for Machinery Failure Prevention Technology, April 2001.
- Installed a video inspection system on the rig capable of following gear damage progression.
- Verified the need for data fusion/fuzzy logic techniques to set threshold limits that discriminate between stages of pitting wear.

Future Plans / Opportunities

- The stated goal was met. Future plans listed on next slide.

POC

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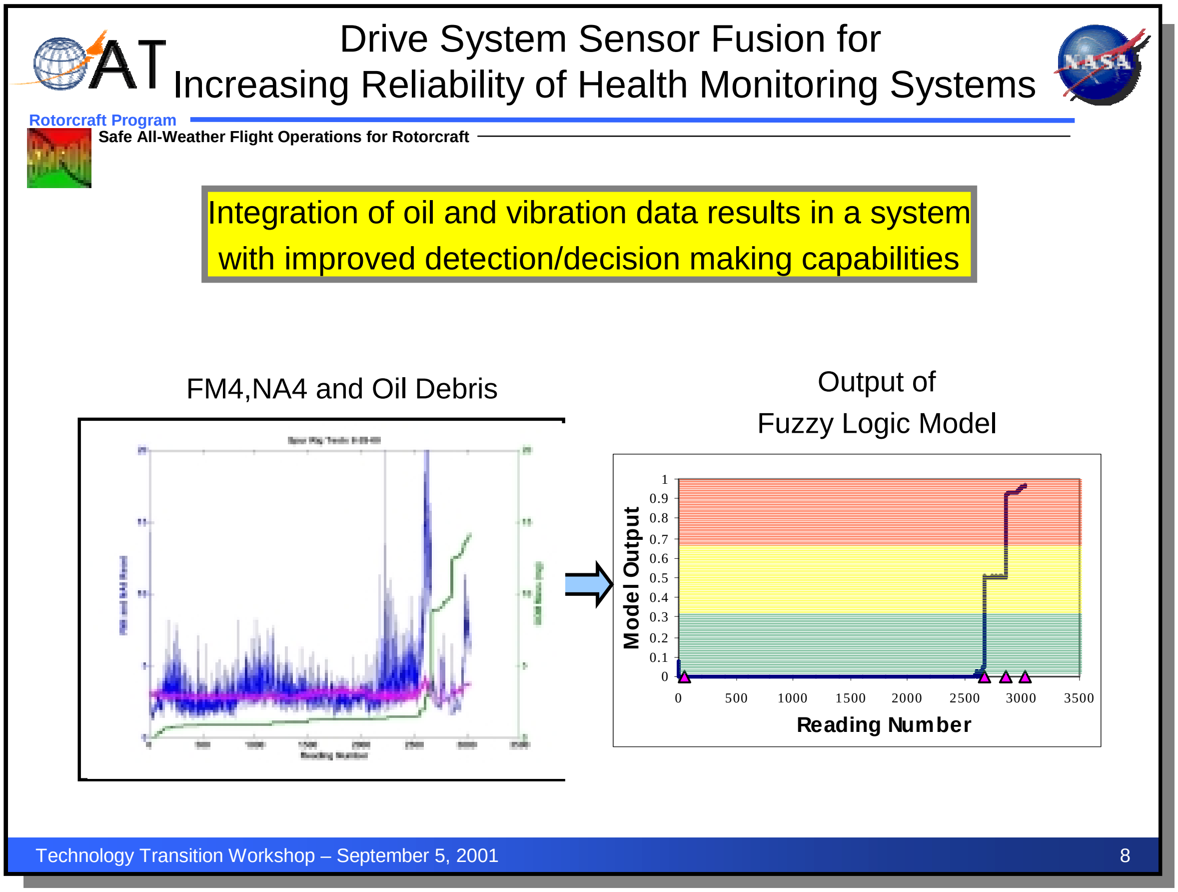

Goal

Integrate oil debris and vibration based gear damage detection techniques into an intelligent health monitoring system model capable of detecting gear pitting damage. Demonstrate integration of the two measurement technologies results in a system with improved detection and decision-making capability.

Accomplishments to Date

Collected vibration and oil debris data from 24 experiments with and without pitting damage.

Verified when using an inductance type, on-line, oil debris sensor, that accumulated mass, as the damage feature predicts gear pitting damage. Combined accumulated mass with fuzzy logic analysis techniques to predict transmission health. Results published in a NASA TM 210936 to be presented at 14th International Congress on Condition Monitoring and Diagnostic Engineering Management, September 2001.

Developed a simple model integrating vibration and oil measurement technologies using fuzzy logic that discriminates between stages of pitting wear. Verified Integration of the two measurement technologies results in a system with improved detection and decision making capabilities. Results published in NASA TM 211126 to be presented at the IEEE Aerospace Conference in March 2002.

Future Plans / Opportunities

Integrate the oil debris and vibration measurement technologies using multisensor data fusion techniques. Data fusion incorporates expert knowledge of the diagnostician into the system, relieving the end user of interpreting large amounts of sensor data. The system provides improved damage detection and decision-making capabilities. Results to be published and presented at the AHS Meeting in June 2002.

POC

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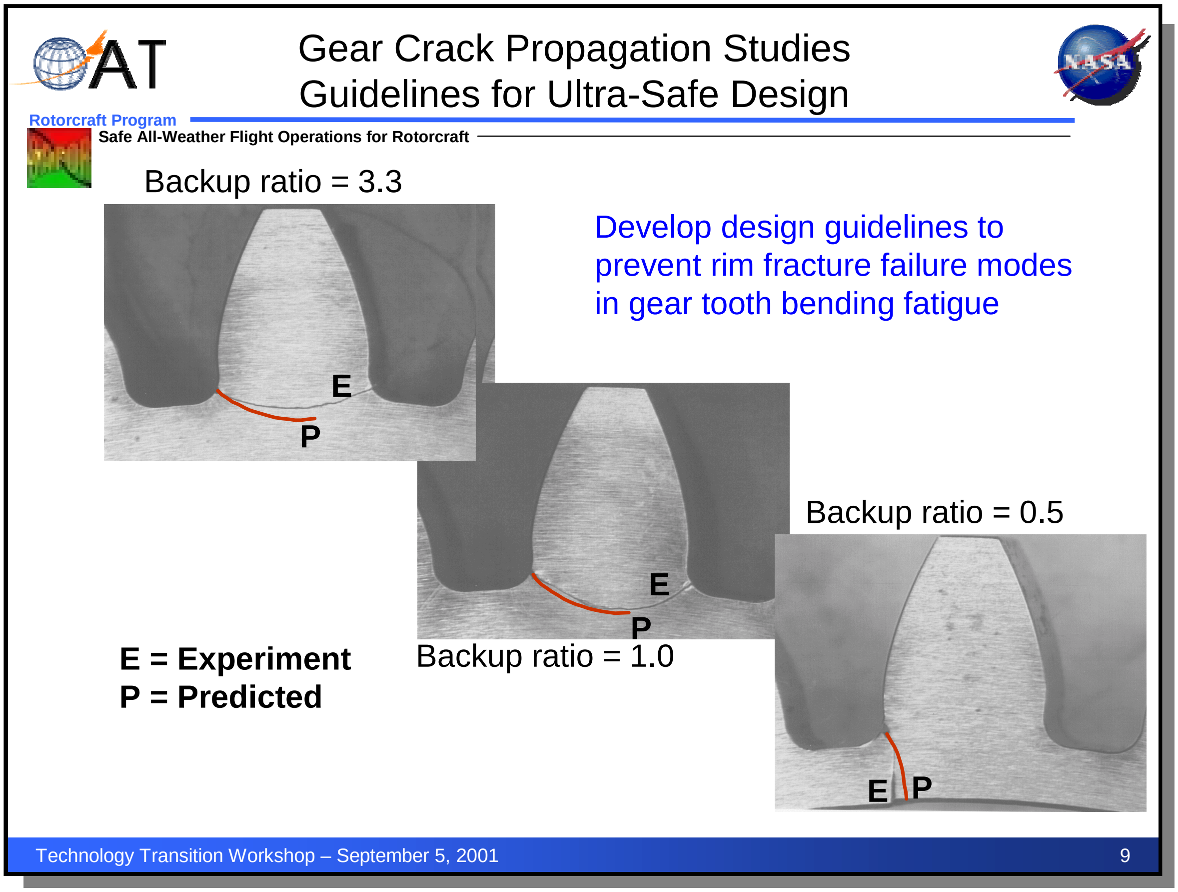

Goal
The goal of this effort was to validate gear crack propagation analysis methods and determine the effect of rim thickness on gear crack propagation path. This was an initial step in developing design guidelines to prevent rim fracture failure modes in gear tooth bending fatigue.

Accomplishments to Date
A finite element based computer program along with principles of linear elastic fracture mechanics simulated gear tooth crack propagation. Gears with various backup ratios (rim thickness divided by tooth height) were tested in a gear fatigue test facility to validate crack path predictions. Good correlation between analysis and experiments was achieved.

Future Plans / Opportunities
Develop design guidelines to prevent rim fracture failure modes in gear tooth bending fatigue

POC
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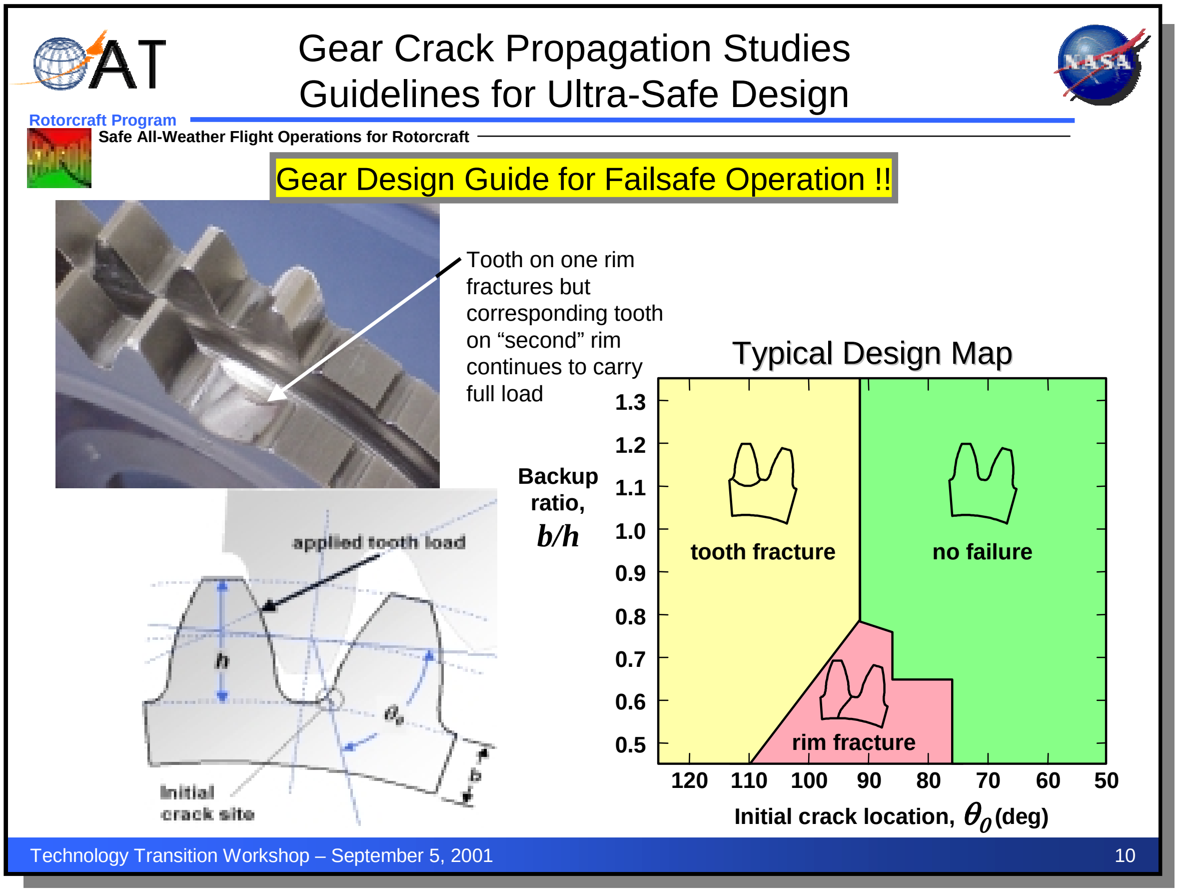

Goal

The goal of this effort was to develop design guidelines to prevent rim fracture failure modes in gear tooth bending fatigue.

Accomplishments to Date

Analysis was performed using the finite element method with principles of linear elastic fracture mechanics. Crack propagation paths were predicted for a variety of gear tooth and rim configurations. The effects of rim and web thicknesses, initial crack locations, and gear tooth geometry factors such as diametral pitch, number of teeth, pitch radius, and tooth pressure angle were considered. Design maps of tooth/rim fracture modes including effects of gear geometry, applied load, crack size, and material properties were developed.

Future Plans / Opportunities

Determine the effects of speed on gear crack propagation direction.

POC

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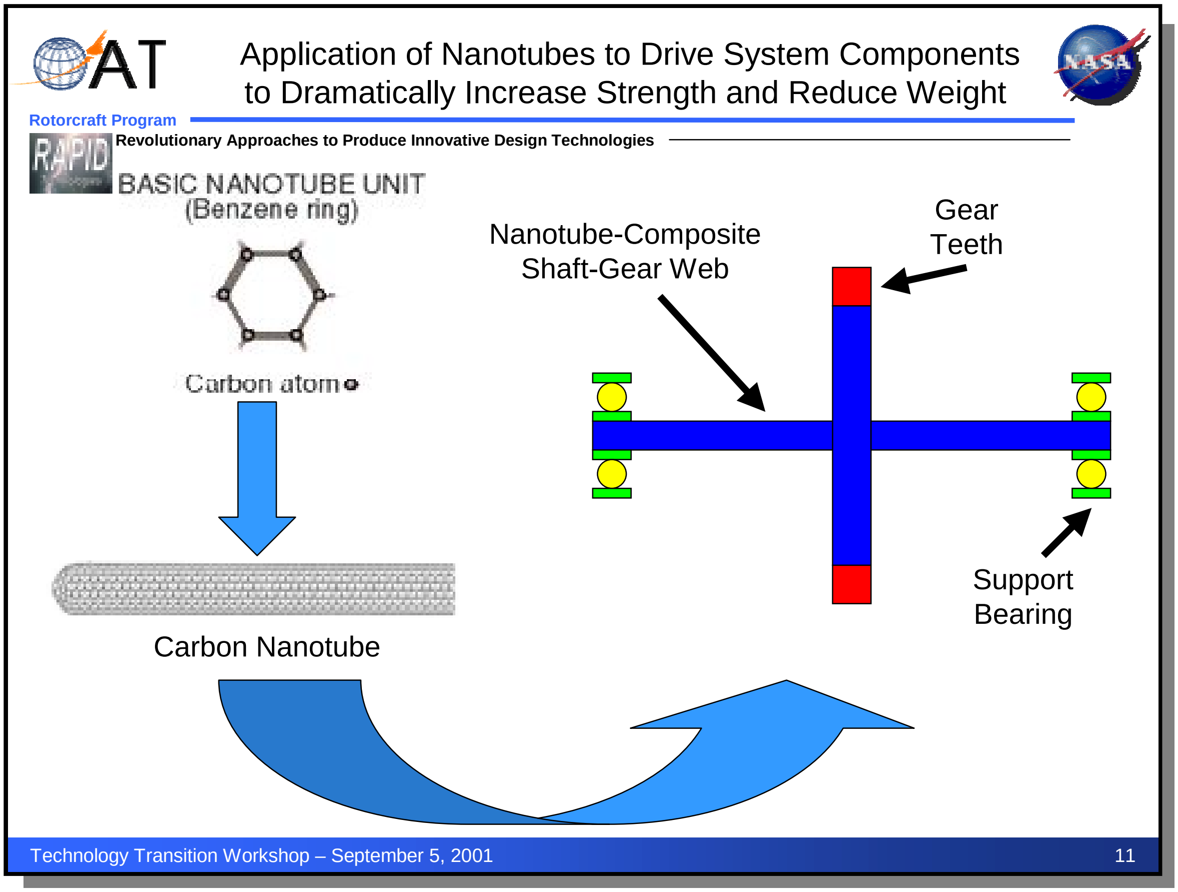

Goal

Develop an understanding of how emerging nanotube technology area could be applied to drive system components in an effort to reduce weight while increasing structural capabilities.

Accomplishments to Date

- Grant at the University of Michigan established, May 2001, Dr. Peretz Friedmann Principal Investigator

Future Plans / Opportunities

- Continue manufacture development to establish large nanotube quantity capability
- Imbed nanotubes manufactured in composite material and conduct basic material strength testing
- Develop proof-of-concept gear-shafting system

POC

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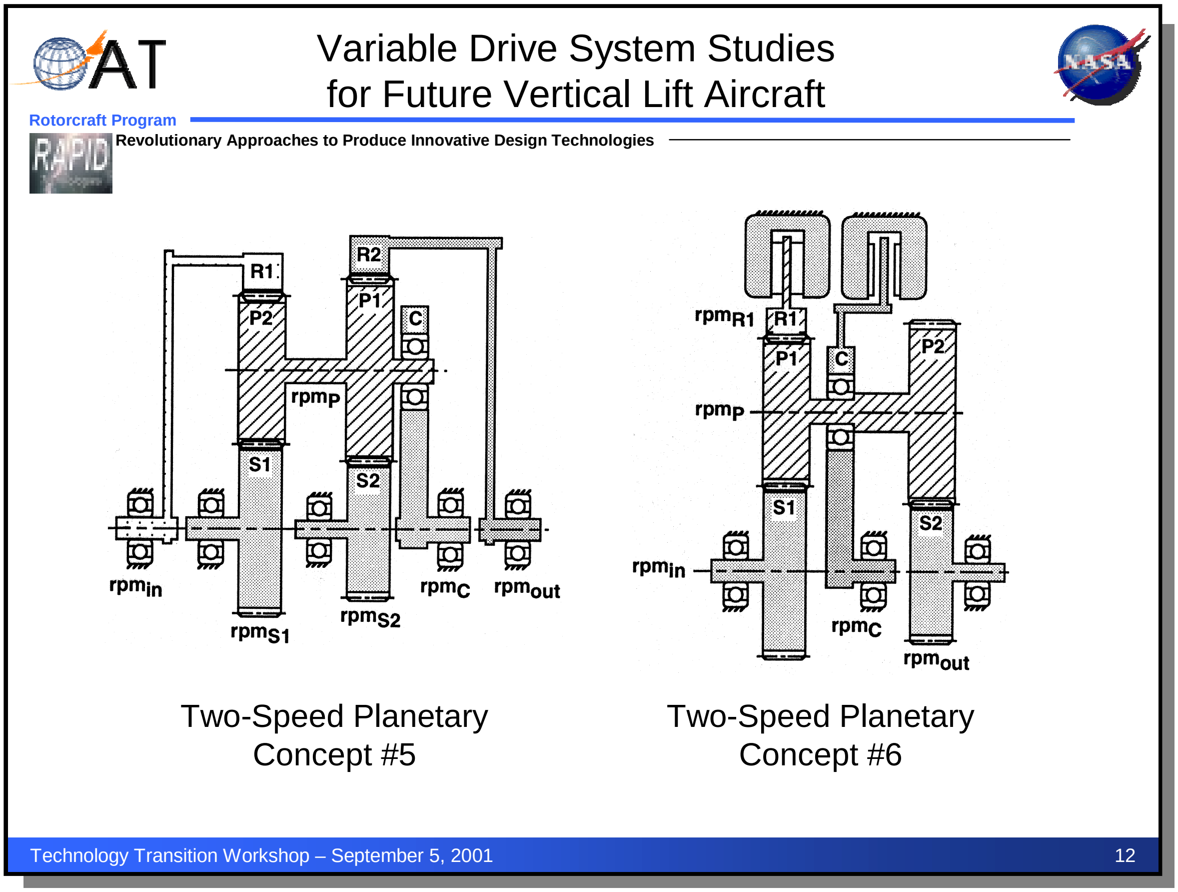

Goal

The goal of this effort is to explore various traditional and non-traditional variable speed concepts for rotorcraft transmissions. By optimizing engine and rotor speeds individually, significant noise reduction can be achieved.

Accomplishments to Date

A research grant has been established with the Ohio Aerospace Institute. The research team consists of two prominent former rotorcraft transmission designers. Various preliminary concepts are currently under investigation.

Future Plans / Opportunities

Down select most promising transmission configuration concepts. Development preliminary designs and quantify benefits of variable speed configuration concepts.

POC

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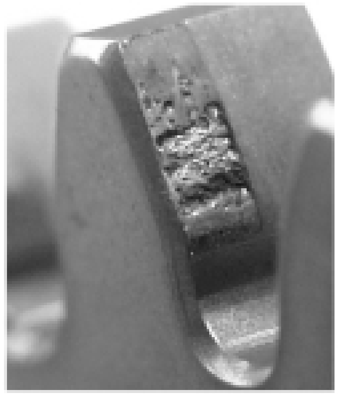
Rotorcraft Program

RAPID Revolutionary Approaches to Produce Innovative Design Technologies

Gear Surface Engineering Research to Increase Power to Weight Metric

Develop surface engineering techniques to increase gear surface fatigue capabilities, and develop an accurate relationship between contact stress and gear life



Technology Transition Workshop – September 5, 2001 13

Goal

The goal of the project has been to increase the power to weight metric (power density) of aircraft gearing. New life theories for gearing are being evaluated and developed. Surface fatigue life is measured using the NASA Glenn Spur Gear Test Rigs.

Accomplishments to Date

NASA Glenn has, over about 30 years, compiled an experimental database for gear surface fatigue life. The database includes more than 900 tests comprising more than 100 billion test cycles. Recently, hard thin surface coatings have been screened, and a limited number of coatings have been found to have excellent adhesion and good durability. New statistical tools are available to optimize test planning and to objectively compare new technologies to the database. Gear fatigue mechanisms and life theories are being proposed and evaluated.

Future Plans / Opportunities

The Spur Gear Fatigue Rigs can be used to benchmark promising new technologies such as new gear steels, duplex hardening, coatings, shot peening, and laser shock peening.

POC

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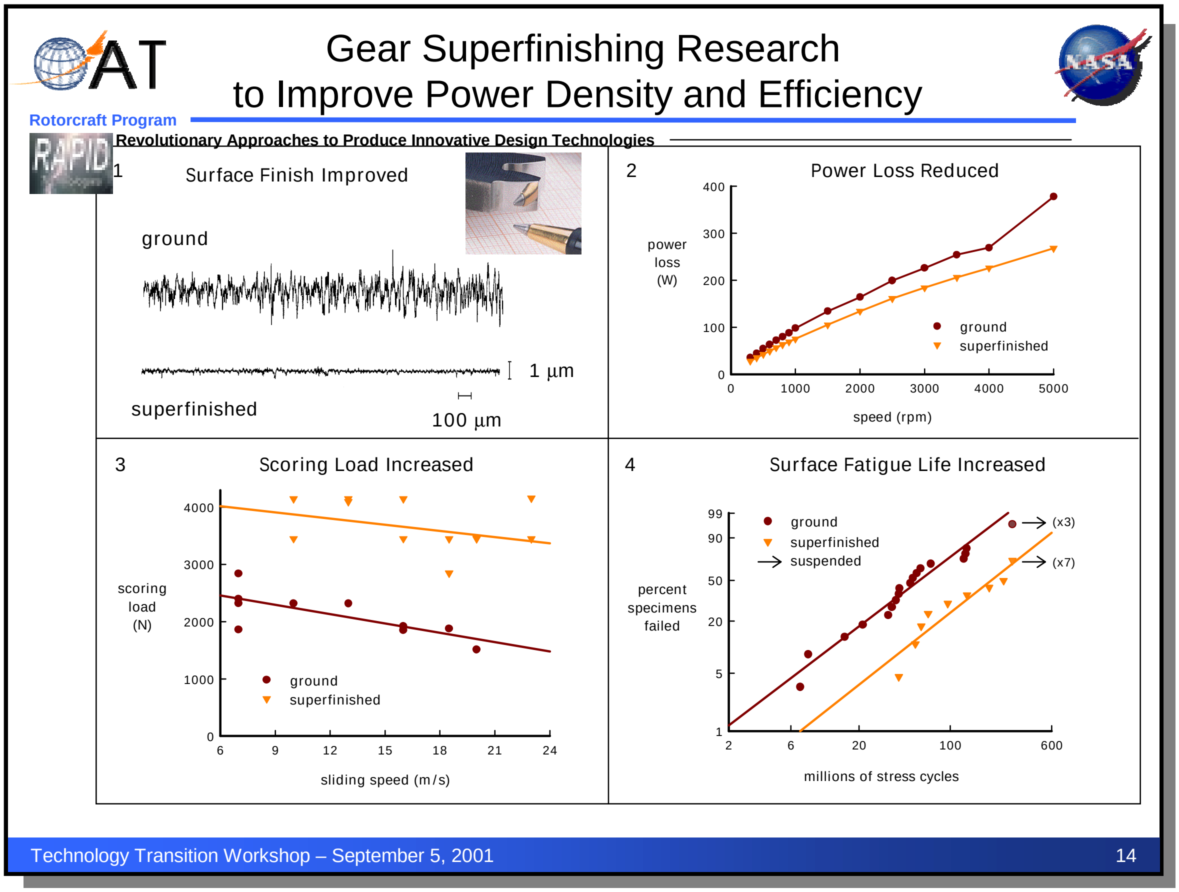

Goal

The goal of the project has been to evaluate the performance benefits that can be attributed to providing a superfinised (mirror-like) gear tooth surface.

Accomplishments to Date

Experiments have shown that gears can be superfinished while maintaining lead and profile geometry. The superfinishing allows for reductions in friction, increased scoring loads, and increased surface fatigue life. Preliminary research to provide superfinished surfaces by grinding rather than polishing has been completed.

Future Plans / Opportunities

Glenn Research Center will be participating in an army funded project to implement superfinishing for army helicopters. Project oversight is provided by a process action team that includes government and industry persons. Interested parties are welcome to provide input to the process action team. Near term projects include the evaluation of surface fatigue and bending fatigue lives of superfinished Pyrowear 53 spur gears. Some testing will also be done to evaluate superfinished spiral bevel gears

POC

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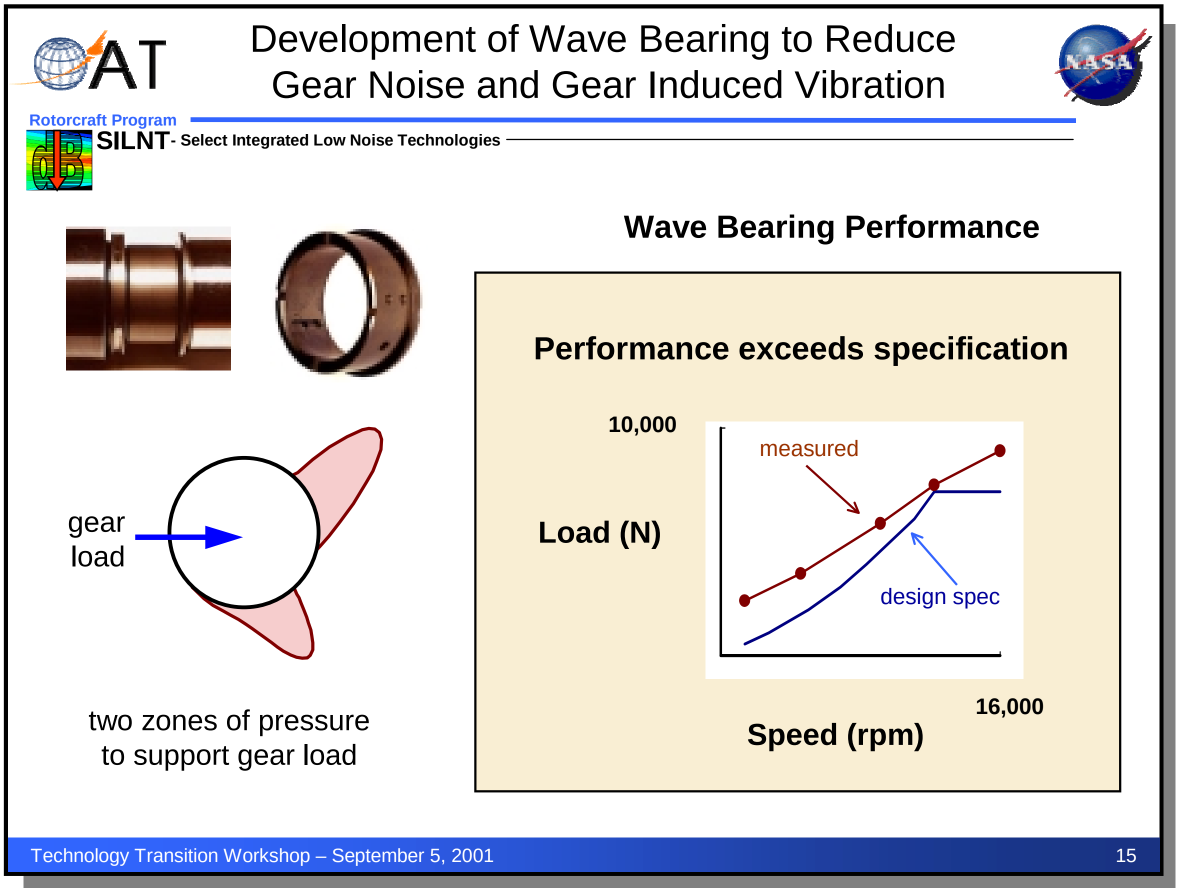

Goal

The goal of the project has been to study the feasibility for application of fluid film bearings to main rotor helicopter transmissions to reduce gear noise.

Accomplishments to Date

A unique fluid film bearing concept, the wave bearing, was developed as part of NASA's general aviation program (GAP). The bearing was designed for an epicyclic gearbox. Measurements show that the bearing is stable in all regimes, robust, and has sufficient load capacity. Design codes have been substantially validated. Design feasibility studies show that the bearing has potential for rotorcraft. The fluid film bearing will provide significant damping for noise reduction.

Future Plans / Opportunities

Detail drawings have been completed for a fluid film wave bearing for NASA Glenn's Gear Noise Rig. Funds from the current base program are not sufficient to manufacture the parts. Completion of the work would allow for a direct comparison of noise reduction by replacing rolling element bearings with fluid film bearings.

POC

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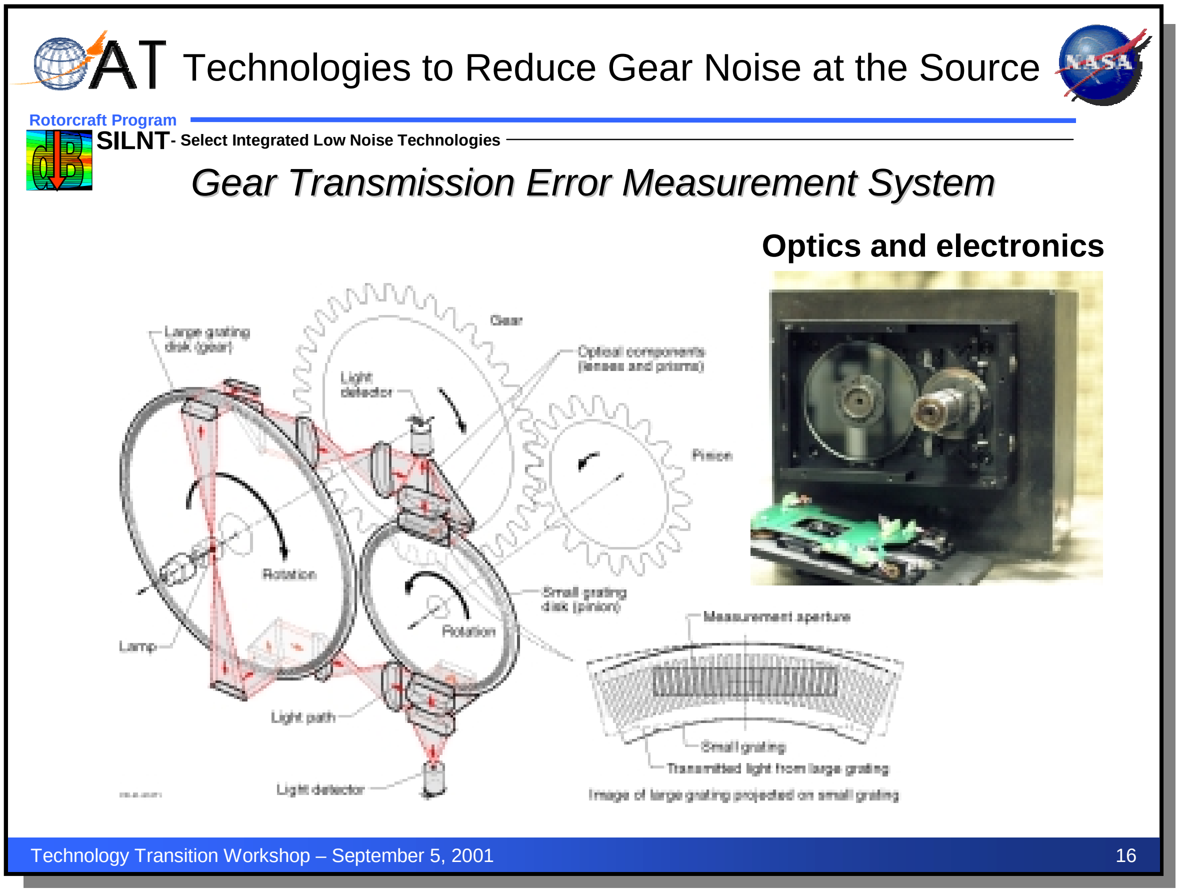

Goal

The goal of this effort was to conduct fundamental experimental research to relate gear design to the resulting generated gear noise. The research community has established a strong correlation of gear transmission error to gear noise. As such, various hypothesis have been proposed to control gear transmission error by appropriate gear system design. The measurement system pictured was developed to validate proposed concepts and codes. The system enables measurement of gear transmission error at high operating speeds and loads. This is a unique capability, with only 3 known systems world-wide with comparable resolution at speed.

Accomplishments to Date

The system has been calibrated and installed into the NASA Glenn gear noise facility. Baseline gear specimens are available for experiments.

Future Plans / Opportunities

The experimental capability is available. The sytem is valuable for fundamental studies of gear dynamics, gear noise and code validation experiments. Limited numbers of gear pairs are available for testing.

POC

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GRC Task Status Summary

Rotorcraft Program

TASKS	Funding Source	Status	Continuation actions
SAFOR			
1. Gear Thermal Management	NASA	On-Going	
2. Drive System Sensor Fusion (HUMS)	NASA	On-going	
3. Gear Crack Propagation Studies	NASA	Phase I complete	
RAPID			
1. Application of Nano-tubes to Drive System Components	NASA	Just Started	
2. Variable Speed Drive Systems	NASA	Just Started	
3. Gear Surface Engineering Research	NASA	On-Going	
SILNT			
1. Development of Wave Bearing to Reduce Gear Noise	NASA	On-Going	
2. Technologies to Reduce Gear Noise at the Source	NASA	On-Going	

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NRTC Project

Rotorcraft Program
National Rotorcraft Technology Center

National Rotorcraft Technology Center

UPN 712 - 50

August 7, 2001

Dr. Stephen E. Dunagan, Project Mgr.

Objectives

- **Briefly describe NRTC collaboration and technology focus areas (for the benefit of potential new government participants)**
- **Provide synoptic view of knowledge product from 6 years of NRTC/RITA collaboration**

Project Overview

Project Goal

- Ensure NASA and DoD access to high TRL rotorcraft technology to meet the needs of the national air transportation system and the national defense.

Technical Objectives

- Implement **design tools** in the domestic rotorcraft industry that will provide faster, higher quality, and more reliable designs for civil and DoD missions
- Implement **integrated design and manufacturing** technology in the production of new rotorcraft to improve performance, quality, and safety.
- Implement high TRL **noise reduction** technology to reduce noise levels in the cabin and the noise footprint in the community.
- Develop and implement rotorcraft operational and certification procedures, and subsystems to improve **aviation safety**.

Approach

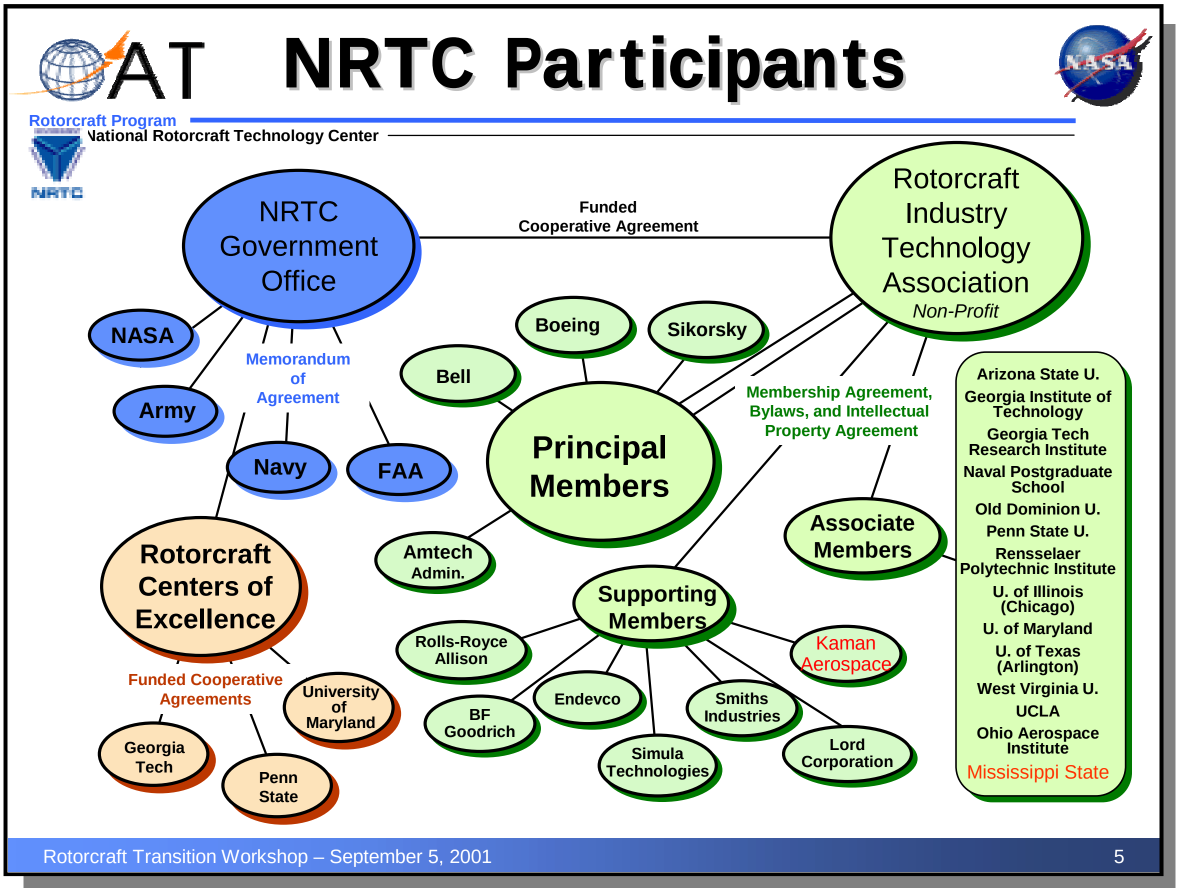
- "Pre-competetive" technical agenda proposed by Industry, with Government advisory review
- 50/50 Cost sharing between Government and Industry
- Sharing of results within Rotorcraft Industry Technical Association (RITA) and Government. (Intellectual Property belongs to RITA)

Benefit

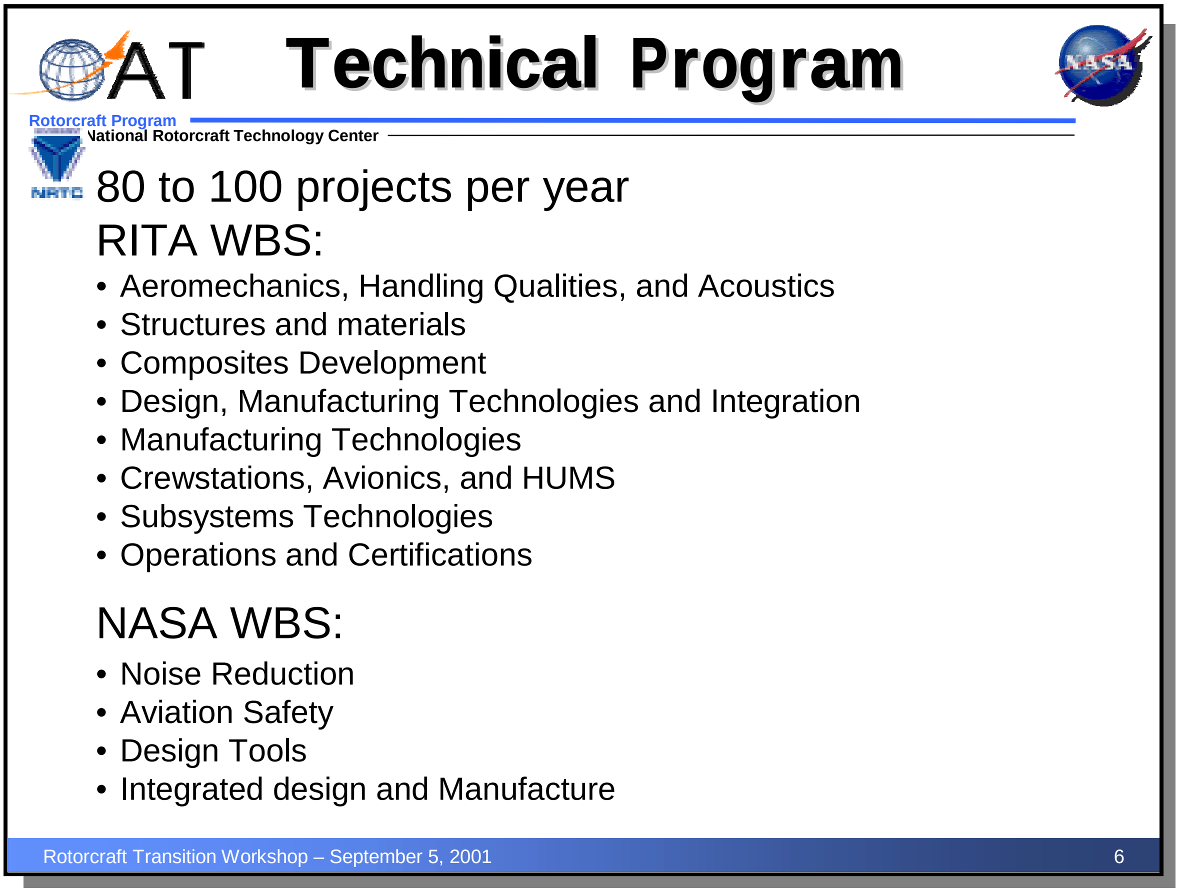
- A globally competitive U.S. rotorcraft industry augmented by Government laboratory and University developed technology

Partners

- National Rotorcraft Technology Center (U.S. Army, U.S. Navy, FAA)
- Rotorcraft Industry Technical Association (Bell, Boeing, Sikorsky, RITA Academic and Supporting members)



Collaboration is a key element in the success of the National Rotorcraft Technology Center. The center is a partnership of government, industry, and academia. Participating government agencies include NASA, the Army, the Navy, and the FAA. NASA is the hosting agency, providing a venue for the government office at Ames Research Center and administrative support for program management. The Army provides significant funding and staff support to interface with other research programs within AFDD and AATD. The Navy and FAA also provide staff support to interface with complementary programs at NAVAIR and the FAA Tech Center. Roles and responsibilities among the government participants are defined within several Memoranda of Understanding. A funded cooperative agreement, developed under the guidelines of the NASA Grants Handbook defines the functional and funding relationships between the government and the rotorcraft industry technology association (RITA). RITA is a non-profit corporation comprised of three principal rotorcraft manufacturers (Bell Textron, Boeing Helicopters, and Sikorsky Aircraft), several supporting members companies who supply components and subsystems to the aircraft industry, and about a dozen associate university members who have a strong research focus in the technology base supporting rotary wing aircraft. Roles and responsibilities among RITA members are defined in the RITA bylaws and operating procedure documents. The NRTC government office also manages a Rotorcraft Centers of Excellence (RCOE) program led by the Army and supported by NASA. This program funds basic research in rotorcraft-related disciplines through cooperative agreements with three academic centers.



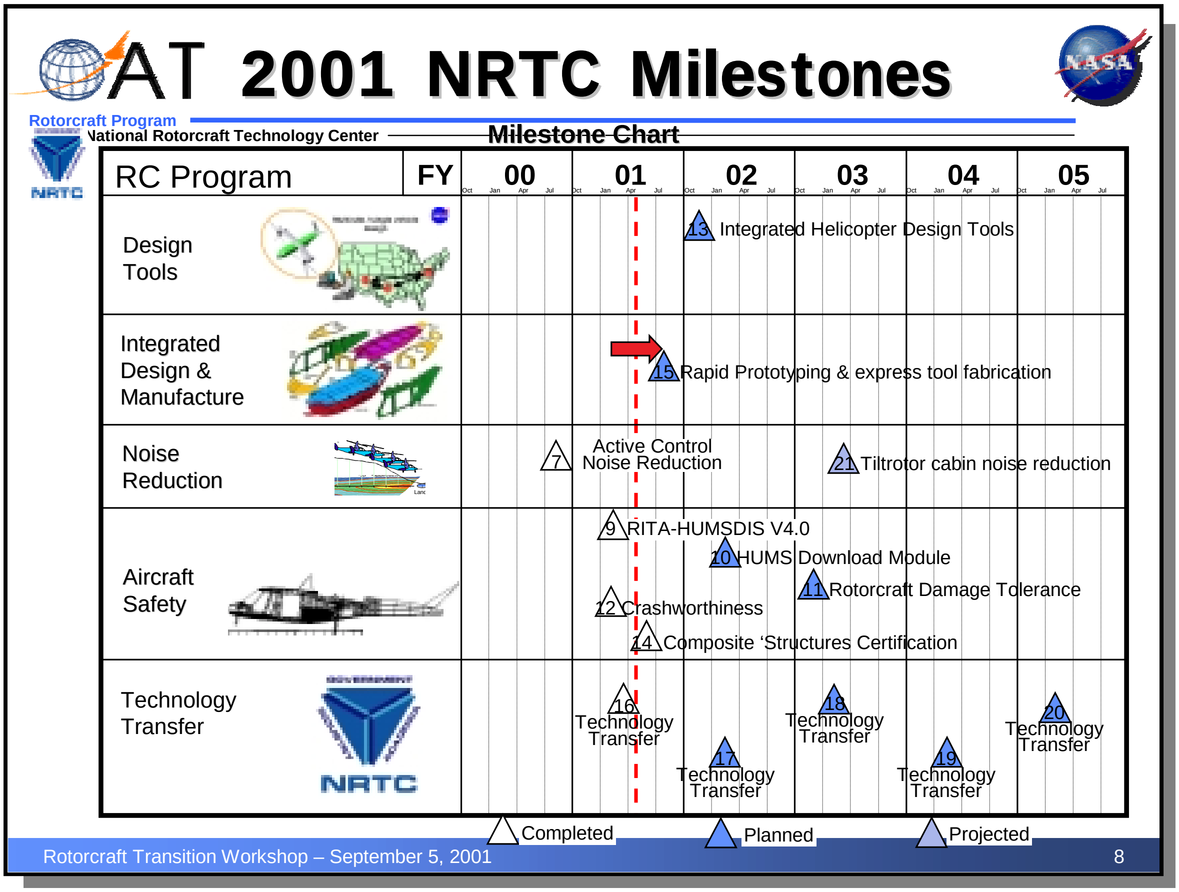
RITA proposes a comprehensive technical program each year comprised of up to 100 individual projects organized according to a work breakout structure that is effective in the context of the industry's requirements. The program is reviewed by the NRTC government office, with feedback to RITA that aims to leverage government assets and knowledge base, and maximize the effectiveness of each project. Each participating government agency may choose to organize the annual technical program according to a WBS that is aligned with agency goals and objectives.

NASA Milestones

Transition to Products

Literature

- Annual reports
- Final Reports
- Publications



Milestones that typically identify technology transition to product are defined collaboratively with RITA. Technical milestones are typically chosen in areas of broad RITA teaming, often at the conclusion of a multi-year sequence of RITA projects (subtasks in NASA NRTC project nomenclature). Technical milestones are reported as tasks within the NASA Rotorcraft Program management system. The primary objective of the NRTC project is technology transfer, both within participating RITA companies and with the government. An single project level annual milestone addressing this objective is the RITA year end review.

Technical Accomplishments

Rotorcraft Program

National Rotorcraft Technology Center

NRTC

GPRA Milestone Completed

Rotorcraft Crashworthiness

M. Smith (Bell), A. Bolukbasi (Boeing), C. Clarke (Sikorsky), L. Labun (Simula)

January 2001

Relevant Milestone: Demonstrate strong correlation of analytic model predictions with full-scale existing and new water/soft-soil-impact test results. (NRTC #12, January, 2001)

Shown:, Actual fuselage damage from full scale crash test compared with prediction of crash damage to UH-1H fuselage for soft soil crash conditions.

Accomplishment / Relation to Milestone and ETO:

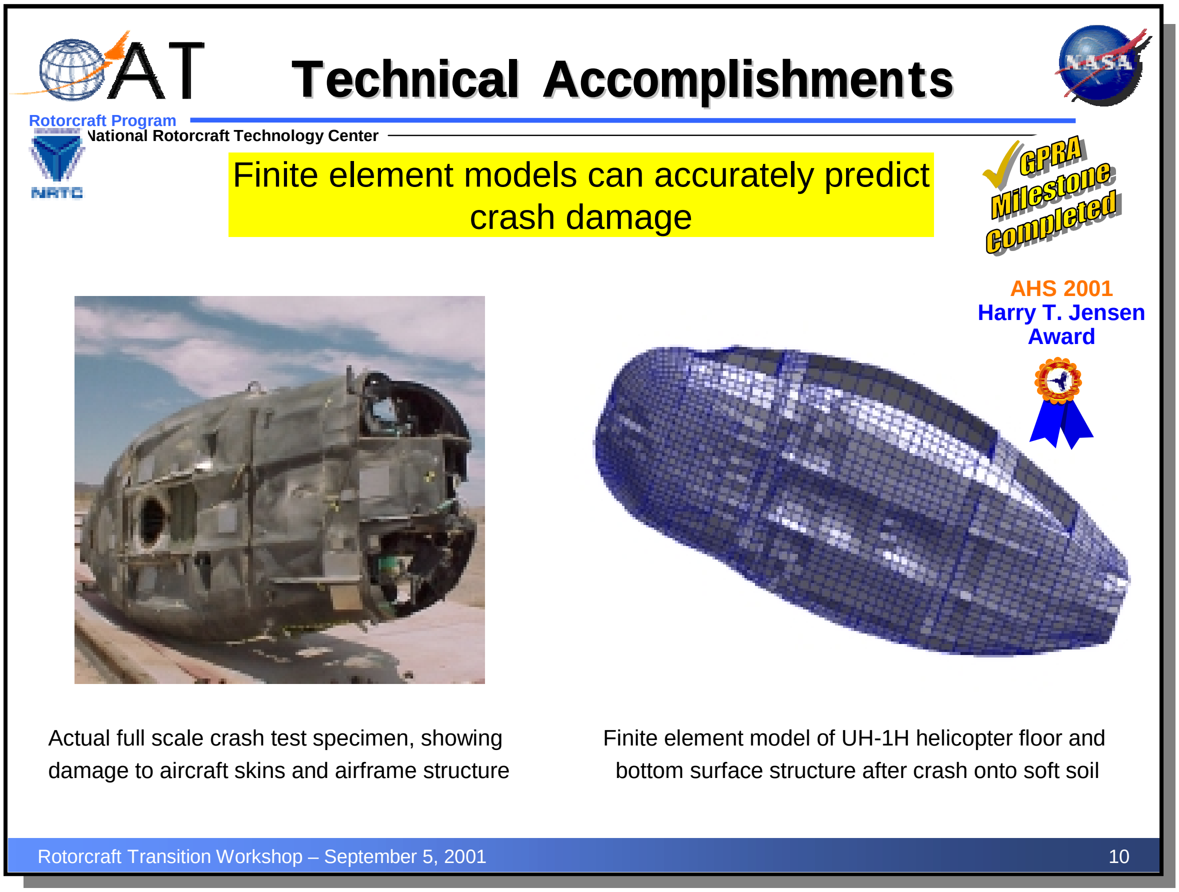
- Finite element modeling has been used to characterize the airframe, aircraft skins, impact media (water and soil), and contact surface. A simulation of the crash tests in both soft soil and water have been computed, along with resulting accelerations and damage to the rotorcraft structure. Crash tests in both water and soft soil have been performed with full scale hardware. Test results have validated the models.
- Cabin and seat G-forces for water and soft soil crashes are more severe than hard surface crashes because landing gear are not as effective. This modeling and test effort has identified the need for a revised standard for energy absorption in seats and floor structures. These results will lead to much better crash survivability for rotorcraft passengers and crew, contributing to the safety enterprise technology objective. This research received the American Helicopter Society 2001 Harry T. Jensen Award for an outstanding contribution to improved helicopter safety.

Future Plans: This analytical capability will be used to design safer rotorcraft. The analysis will be extended to include the special structural requirements of large rotorcraft. The industry will develop a new generation of energy absorbing metal and composite structures in the landing gear, floor and seats.

ETO: Safety

Rotorcraft Transition Workshop – September 5, 2001 9

This is an example of the way technical milestones are reported to NASA management. These 2-page summaries are available for all Project milestones.



A descriptive graphic is included with each “2-pager”

At the end of the first 5-year NRTC-RITA funded cooperative agreement a series of slides was prepared to document the transition of technology to aircraft systems. This slide summarized technologies incorporated into the Sikorsky S-76. A concentration in safety- related technologies may be noted.

Technology Commercialization

Rotorcraft Program

National Rotorcraft Technology Center

NRTC

Bell Agusta BA-609 Civil Tiltrotor

- NRTC/RITA collaboration has contributed significantly to the development of a new, civil tiltrotor aircraft that will revolutionize vertical-flight capabilities

- **Technology enhancements for the BA-609:**
  - Composite structural design and manufacture: 1) Data for defining design allowables and (2) Many processing technologies
  - Special handling-qualities / control-law development …. for use with offshore, oil-platform operations
  - Precision, decelerating, steep-angle DGPS approaches: (1) Reduce community noise by up to 10 dB and (2) Enhance tiltrotor / heliport IMC operations
  - Cabin-noise prediction methodology to guide design
  - Advanced rotor-ice-protection system -- tunnel data and analytic methods

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The BA 609 represents state-of-the-art design for a composite aircraft, within the civil transport design domain of primary interest to NASA. A host of new composite materials, fabrication processes, and component applications are incorporated into its design. The light weight metal parts fabricated with high speed machining technologies are also incorporated where the cost benefit is clear. Handling qualities have been analyzed as well, and are particularly important in view of V-22 experience. Noise reduction both inside the cabin and in the external community, coupled with ice protection systems will contribute to the wide utility of this aircraft.

Technology Commercialization

Rotorcraft Program

National Rotorcraft Technology Center

- **NRTC/RITA collaboration has contributed significantly to the development of the RAH-66, a helicopter that will revolutionize vertical-flight capability in the battlefield**

Boeing/Sikorsky RAH-66 Comanche

- **These technology enhancements are incorporated or being evaluated for use in the RAH-66 aircraft:**
  - ➔ Integrated Helicopter Design Tools (IHDT)
  - ➔ Composite design/manufacture:
    - Improved design criteria …. for defining material/design allowables
    - Advanced Resin Transfer Molding (RTM) … of various structural and non-structural components
    - Paste-adhesive joining process … for attaching stiffeners/frames to thin skins

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The Boeing/SikorskyComanche design has leveraged significantly off the web-based design tools developed under the Integrated Helicopter Design Technology (IHDT) and follow on Technology for Rotorcraft Integrated Analysis and Design (TRIAD) efforts within RITA and the government. The aircraft uses a number of advanced composite materials and processes.

Rotorcraft Program

National Rotorcraft Technology Center

NRTC

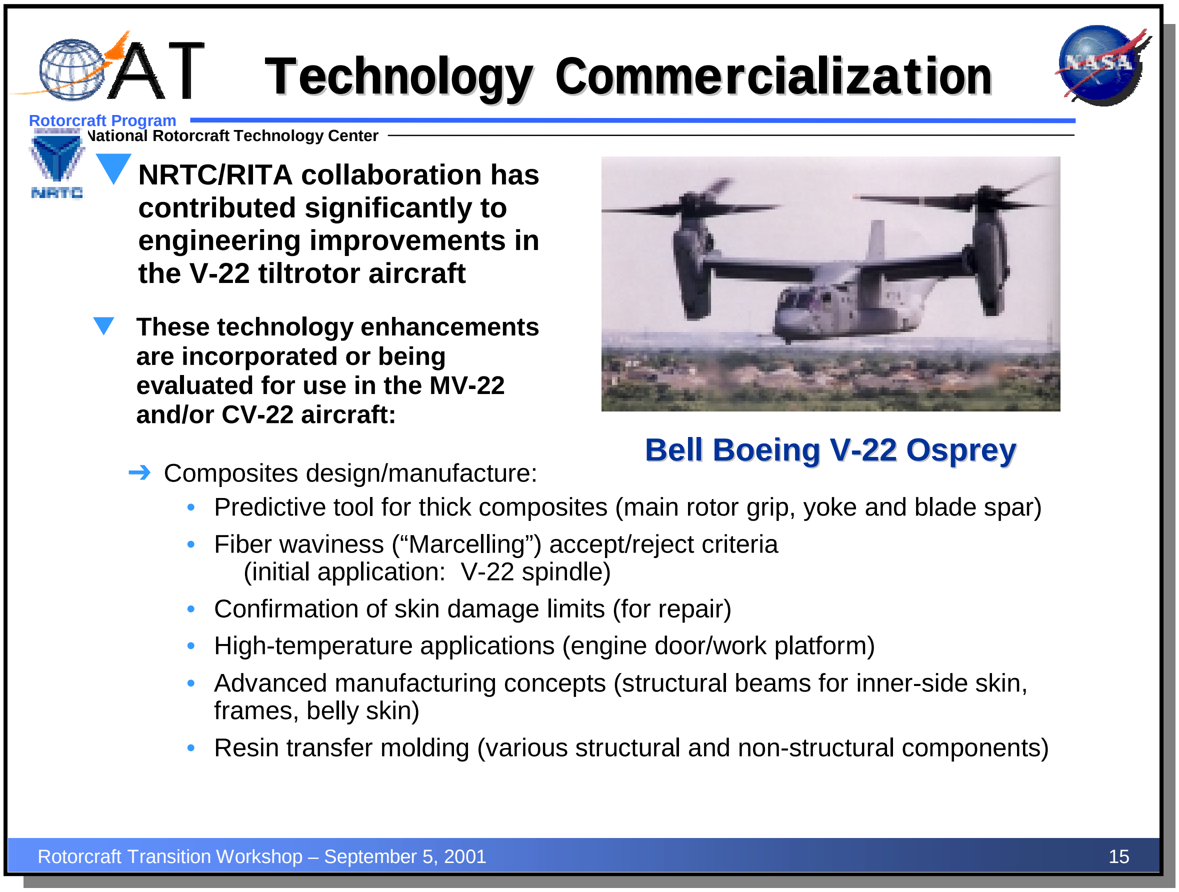
Technology Commercialization

- Advanced Ice Protection System for engine inlet …. based on wind-tunnel test results at NASA Glenn
- Improved directional-control characteristics … based on fan-in-fin unsteady-aerodynamics research
- Fly-by-wire flight control system with tactile pilot cueing ….. from active, three-axis sidestick controller work
- Health and Usage Monitoring Systems (HUMS) …. an integral part of aircraft systems (… benefiting safety and cost)

Boeing/Sikorsky RAH-66 Comanche (Continued)

Rotorcraft Transition Workshop – September 5, 2001 14

Comanche specifications also demand extreme agility, requiring new technologies for flight control and man-machine interface. HUMS technology will provide critical flight safety information to the pilot and improve the long term affordability of the weapons system.



The V-22 program has significantly advanced the state-of-the-art in composite aircraft design. Technical challenges have been overcome which permit designers to capitalize on the use of composites for everything from very thick structures such as rotor hubs and drive shafts to very thin structures such as post-buckled aircraft skins. Other materials development successes include grid stiffened components capable of surviving high temperature environments, and resin transfer molded processes for low cost non-structural components.

RAT Technology Commercialization

Rotorcraft Program
National Rotorcraft Technology Center

NRTC

- Flow-field-analysis tool (Hybrid LES/RANS)…. correcting flow separation, tail buffet, and rotor/fuselage interactions
- High-speed titanium machining --- blade-fold mechanism (6 per aircraft)

Bell Boeing V-22 Osprey (Continued)

- Avionics tailoring ….. aided by “Interference Cancellation” report (to evaluate addition of third VHF/UHF radio in MV-22)
- Avionics open architecture guidelines -- require-ments for a new radar system for CV-22
- Composite airframe lightning protection… improved by new skin panel edge treatment and connector bonding process
- Tiltrotor-aircraft download-reduction concept (flight-validated… with structural/weight/cost analysis)
- Precision Pathway Terminal Guidance (PPTG) flight symbology for V/STOL aircraft

Rotorcraft Transition Workshop – September 5, 2001 16

RITA technology has contributes to the solution of several other challenges for the V-22, including analysis tools to alleviate tail buffeting, avionics architecture and RFI standards, precision navigation capabilities, and aircraft skin treatments to mitigate the damage caused by lightning strike.

The Blackhawk and Seahawk upgrades have exercised the distributed design features of the IHDT and TRIAD tools developed by RITA. High-speed machining technology permits the use of large monolithic thin-wall ultralight components that improve reliability and reduce fabrication costs. Advances in the understand of damage tolerance in metal components subjected to the unique load spectrum encountered in rotorcraft primary load-path components, coupled with HUMS technology to monitor and record life usage, will permit the safer and more economical design and maintenance of these components during the fleet's extended service life. Specific sub-systems for vibration reduction and ice mitigation improve the safety and effectiveness of the H-60 aircraft.

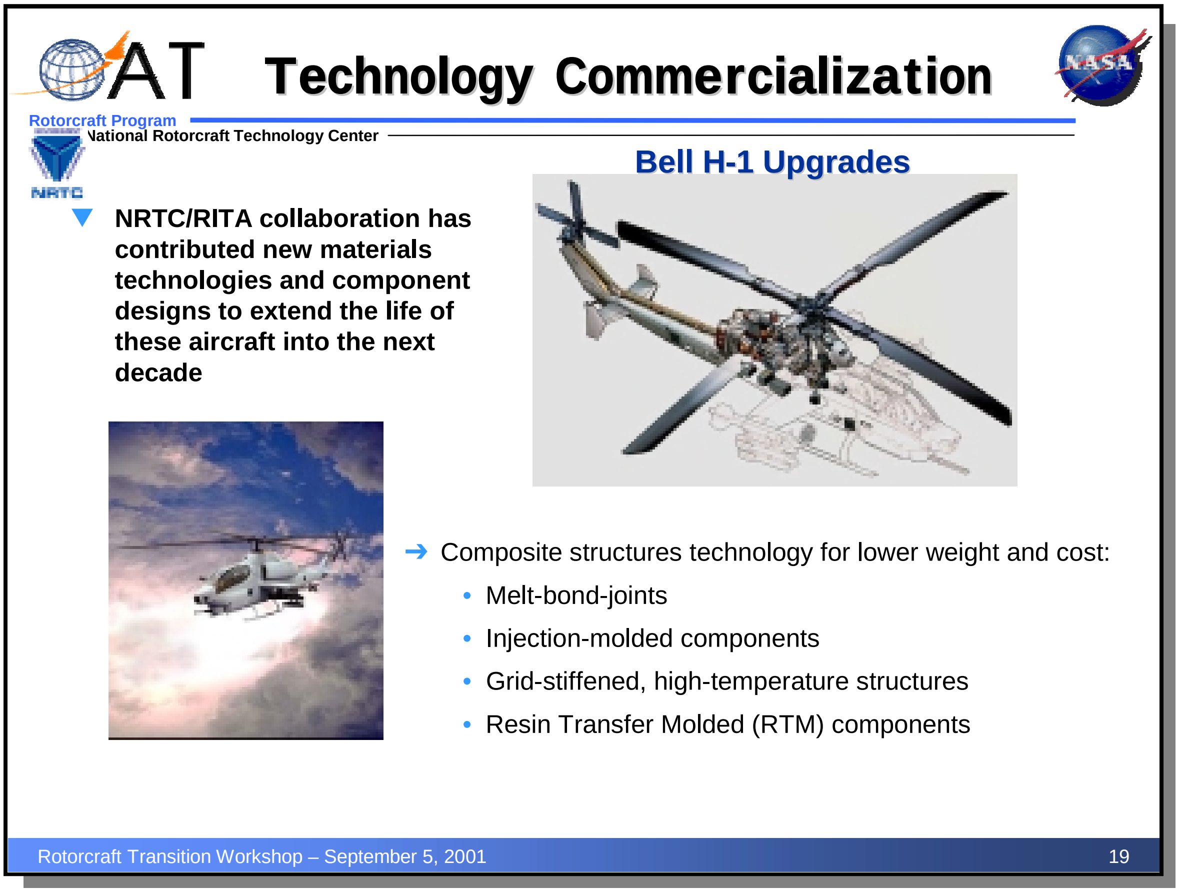
Technology Commercialization

Boeing AH-64 Apache

- NRTC/RITA collaboration has contributed technologies that improve the aircraft weight/ performance, subsystems design and maintenance/ aircraft readiness

- ➔ Variable-speed, vapor-cycle technology … more efficient power use for avionics cooling
- ➔ Composites technology: adaptive cure and cure-control monitoring for new composite blades
- ➔ Damage-tolerance methodology/data for life prediction of components (i.e., safety and lower-cost maintenance)

The Apache utilizes RITA technology in it’s new composite blades. A light-weight, high efficiency vapor cycle cooling system helps keep the pilot and avionics cool, and damage tolerance methodologies will improve the safety record for the aircraft and reduce fleet operating costs.



Upgrades to the Cobra and Huey include RITA developed composite materials and processes that reduce weight and cost to manufacture.

OAT Technology Commercialization

Rotorcraft Program
National Rotorcraft Technology Center

- **NRTC/RITA Collaboration has produced technology enhancements that are incorporated or being evaluated for use in the Sikorsky S-76 helicopter**
- **These technologies have a direct impact on the NASA OAT goals for noise reduction, and aircraft safety:**

Sikorsky S-76 Series

- ➔ New approach procedures ……. for HAI Fly Neighborly Guide/Program and S-76 Operators Conference/Newsletters
- ➔ Cabin tonal-noise-control technology .... demonstrated
- ➔ FAA RPTERPS criteria for precision, decelerating, steep-angle DGPS approaches ……. that reduce community noise levels and enhance helicopter/heliport IMC operations (2000 AHS Frederick L. Feinberg Award)
- ➔ Damage-tolerance technology ……. determines inspection intervals on S-76C+ engine
- ➔ Enhanced ground-proximity-warning system (EGPWS) for safety….. demonstrated system; provided draft FAA Advisory Circular for implementation (2001 AHS Howard Hughes Award)

Rotorcraft Transition Workshop – September 5, 2001 20

RITA has developed several flight operations enhancements for the S-76 which will alleviate community noise and reduce the number of accidents resulting from controlled flight into terrain. Interior noise reduction subsystems technology has significantly reduced drivetrain noise transmitted to the passenger compartment. Damage tolerance methodologies will also contribute to safe operation and reduced costs.

Rotorcraft Program

National Rotorcraft Technology Center

NRTC

Technology Commercialization

Boeing CH-47 Chinook

- **NRTC/RITA collaboration has contributed new materials technologies and component designs to increase safety, quiet the ride, and extend the life of these aircraft into the next decade**

  - Resin transfer molding of primary structure (Improved Fuel-Isolation System *[IFIS]* beams)
  - HUMS open system-interface specifications, advanced-sensor technology, and cost/benefits model
  - Interior-noise prediction and reduction

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The Chinook is another aircraft that is being utilized far beyond it's intended design life. RITA HUMS technology will monitor and manage the performance of aging airframe, drive-train, and power-plant components. Composite materials and noise reduction technologies have been applied to this aircraft also.

AT Technology Commercialization

Rotorcraft Program
National Rotorcraft Technology Center

- **NRTC/RITA collaboration has produced technology enhancements for Bell 407, 412, and 427 aircraft:**
  - ➔ Composite-material structural design and manufacture:
    …….. data defining material-design allowables
    …….. numerous processing technologies
  - ➔ Improved resin-transfer molding (RTM) composites
  - ➔ Superplastic-forming of aluminum
  - ➔ High-speed machining of highly loaded, titanium parts

- **Composite-materials and metal-processing techniques help build safe aircraft**

Bell 400 Series

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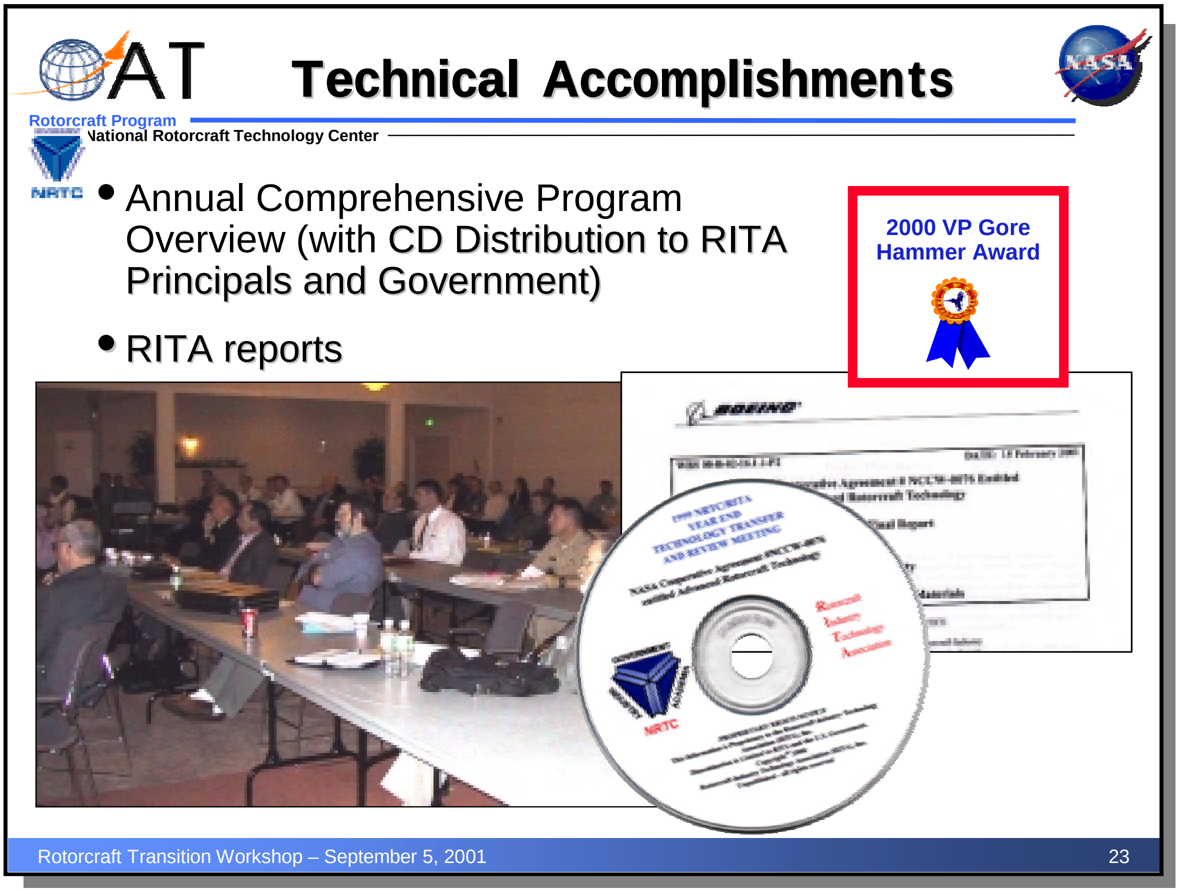
Bell commercial helicopters incorporate several RITA developed materials and fabrication process technologies.



The annual RITA Year End Review serves as the principal project level milestone in the NASA NRTC Project, with "technology transfer" , among all government and RITA participants as the stated objective. The RITA Technical Advisory Committee organizes and leads this meeting. Each RITA project is reviewed against it's proposed objectives, budget, and schedule. Accomplishments and findings are presented and discussed, with emphasis on information that can be shared to good advantage among all interested RITA members. A CD of all the (RITA proprietary) presentation materials is produced each year and distributed to the RITA principal members and throughout the government. This series of CDs, (1997 through 2001) represents an important archive of the knowledge product of this NASA project.

CAT Project Final Reports

Rotorcraft Program
National Rotorcraft Technology Center
NRTC

Outline for Final Report

- Industry/DoD Need(s)
- Objective(s)
- Approach [*A separate section for each title]*
  - Technical Approach
  - Technology Dissemination
- Progress and Accomplishments
- Tasks/Schedule/Cost
- Matching Industry Contributions
- Research Products (Military & Industry Benefits)
- Key Personnel
- Industry and Government Collaboration
- Relevant Publications / Technical Reports

Overview of final reports 1995-2001

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The Funded Cooperative Agreement that defines the relationship between the NRTC government office and RITA provides for a series of reports to be delivered to the Government as part of the life cycle of each RITA project. In addition to periodic status reports which permit the government to monitor progress against the project objectives and provide guidance and problem solving assistance, a comprehensive final report is provided at the end of each (single or multi-year) RITA project series. Each final report reviews objectives, funding, and technical approach, identifies points of contact, documents findings, and references supporting reports and data. This series of RITA proprietary reports is available for distribution within the government and represents another important archive for the NASA NRTC project knowledge product.

Open Literature Pubs

- Bibliography provided with more than 80 citations
- RITA TAC screens all publications to ensure that proprietary material stays within RITA
- Most effective use of open literature publications relates to establishing standards

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